Queen Mary and Westfield College
University of London
School of Biological and Chemical Sciences

The Taxonomy, Bathymetric Distribution and Species Composition of Halocyprid Ostracods in the Gulf of Oman

PhD Thesis

Carol D. Graves

March 2012

Abstract

Halocyprid ostracods are small abundant crustaceans in marine mesozooplankton communities. They feed on the detrital fluxes sinking from the surface into the deep ocean and so play an important ecological role in the food webs and carbon fluxes.

During the northeast monsoon of 1997, plankton samples were collected from the Gulf of Oman, using a multiple rectangular midwater trawl. A day and night series of bathymetrically stratified plankton samples was taken to a depth of 2000 m. Ostracods were analysed from these samples.

The subsurface samples contained two size groups of *Euconchoecia* that could not be assigned to any previously described species. Two new species, *Euconchoecia omanensis* and *E. hormuzensis* are described.

Below 1500 m a species was collected that resembled *Paraconchoecia mamillata* Müller, 1906 found in the Atlantic. However, both differ significantly from *Paraconchoecia spinifera*, the type species of the genus *Paraconchoecia*. Consequently a new genus, *Mamilloecia*, is established to accommodate the Atlantic species as *Mamilloecia mamillata* and the new Oman species as *Mamilloecia indica*.

Ostracods from the 1600 m sample have been assigned to a new genus and species as *Huxleyoecia muscatensis*.

At 2000 m ostracods were identified as *Mollicia minki* Poulsen, 1973. However, the generic name was preoccupied by *Mollicia* Marples, 1964 a genus of jumping spider. So an alternative name *Mollicoecia* is proposed to replace *Mollicia* Poulsen, 1973. The Oman species of *Mollicoecia minki* Poulsen 1973, new combination, is comprehensively re-described.

Ostracod abundance was greatest above 200 m and sharply declined from 400 – 1000 m coinciding with the extreme oxygen minimum zone. The greatest species richness was below this oxygen minimum zone at 1400 m. These data contrast with those from 30ºN 23ºW in the Atlantic Ocean, where there is no extreme oxygen minimum and ostracod abundance peaked at 200 – 300 m and species richness peaked at 700 m.

Contents

Graves C. 2011. Redescription of *Euconchoecia chierchiae* Müller, 1890 and *Euconchoecia aculeata* (Scott, 1894) (Halocyprididae, Ostracoda) from the Atlantic, and Descriptions of Two Novel Species of *Euconchoecia* Müller 1890, from the Gulf of Oman. Journal of Natural History, 45, 29-32, 1937-1981.

Graves C. 2012. *Mamilloecia indica* (Halocyprididae:Ostracoda) a new genus and species from the Northwest Indian Ocean, Journal of Natural History, 46, 9-10, 516-556.

Chapter 1

1.1 Halocyprid Ostracods

Halocyprid ostracods are small crustaceans, typically 0.5 – 3 mm, and extremely abundant in marine mesozooplankton communities. They occur in all oceans and at most depths throughout the water column. They feed on the detrital flux sinking from the surface into the deep ocean and hence play an important ecological role in the food webs and carbon fluxes (Angel et al. 2007). Halocyprid ostracods lack obvious eyes yet may undergo vertical migration synchronized with the diurnal light cycle.

The first planktonic halocyprid ostracod, the most common of the oceanic ostracods groups, was described by Dana (1849). Our knowledge of planktonic ostracods grew slowly at first. In his Challenger Report Brady (1880) mentioned only three planktonic halocyprid species, although by that time ten halocyprid species were known. In the two decades from 1890 – 1909, Claus and Müller published the first descriptions of most of the currently known species and their contributions established the basic systematics of the group (Claus 1891, Müller, 1894, 1906, 1912). However, Müller's systematics was based only on the characteristics of the carapace and first and second antennae (Müller, 1890); consequently he classified most of the Conchoeciinae species in a single genus *Conchoecia*, Müller, 1906. Skogsberg (1920) reviewing the early literature, alluded to deficiencies in many of the early descriptions, which even then were causing confusion between pairs or groups of closely related species. Much of this ambiguity about species identity persists despite over 200 species of halocyprid ostracod having been described (Angel et al. 2007).

Poulsen (1969a) in his revision of halocyprid ostracods classified halocyprids into:

Family Halocypridae Dana, 1853

1) sub-family Archiconchoecinae Poulsen, 1969

genus: *Archiconchoecia* Müller, 1894

2) sub-family Euconchoeciinae Poulsen, 1969

genera: *Euconchoecia* Muller, 1890, *Bathyconchoecia* Deevey, 1968

3) sub-family Halocyprinae Dana, 1849

genera: *Halocypris* Dana, 1852, *Halocypria* Claus 1874, *Fellia* Poulsen, 1969

4) sub-family Conchoeciinae Claus, 1891

genus: *Conchoecia* Claus, 1874

But since 1969 many more genera have been added to this list, partly as a result of the splitting of these 'old' genera as the characteristics of other limbs have been investigated, and partly as a result of new discoveries.

1.2 Morphology of Halocyprid Ostracods

A halocyprid ostracod has an outer carapace that is formed into two valves hinged along the dorsal margin and completely encloses the body (Figure 1.1). Species of ostracod are identified using morphological criteria as employed by Müller (1906), starting with the shape of the carapace, which may be globular, cylindrical or laterally compressed. The carapace surface may be smooth, pitted or sculptured, with females and males of the same species typically having a slightly different carapace shape and size.

Other taxonomically important carapace features include the positions of the two large groups of glands that are located on each valve of the carapace, which can be either symmetrically or asymmetrically positioned and the setation of the first and second antennae (Müller 1906). However, Chavtur (2003) and Chavtur and Stovbun (2003) have demonstrated the importance of characteristics of other limbs in species identification (Figure 1.2).

The frontal organ (Figure 1.3) is an unpaired appendage positioned between the pair of first antennae and may have a chemosensory function. It is variable in structure and can differ between genera and species. It is sexually dimorphic in many genera: in males the organ is differentiated into a stem and an end piece, the capitulum, which is divided from the stem by a septum, but in females the stem and capitulum are often fused.

The first antennae (Figure 1.3) are uniramous, typically five segmented, with the two terminal segments bearing long setae. Variations in the number of setae distinguish the different subfamilies, and variation in the lengths of these setae, together with their armature are important taxonomic characters that are used to distinguish between species. The first antennae have a largely sensory function and are held vertically downward through the anterior gape of the carapace during swimming (Iles 1961). They are sexually dimorphic and may also have a secondary sexual function.

The second antennae (Figure 1.4A) are biramous, comprising a robust protopodite, a 3-segmented endopodite and a 9-segmented exopodite. The large and muscular protopodite provides the power for swimming. The first exopodite segment is elongate and there are eight short segments, each bearing a long swimming seta with a double row of long hairs: the terminal exopodite segment has one or two shorter setae. The structure of the endopodite is sexually dimorphic and can be taxonomically important. In both sexes, the first segment of the endopodite bears two short pointed setae, which may or may not have hairs or spinules. The presence or absence of a process proximal to the insertions of the setae, the processus mamillaris, differentiates between the halocyprid subfamilies. In the female, the second and third segments of the endopodite are fused, whilst in the male the third segment is developed into a hooked appendage (Figure 1.4 B, C). The terminal segment of both sexes supports a number of setae, the lengths of which are species specific. The main function of the second antenna is swimming. During swimming, the oar-like exopodite is extended through the incisure beneath the rostrum, which acts like a rowlock for the backward power stroke (Iles 1961). Throughout the backward stroke the long hairs on the swimming setae splay and then feather during the recovery stroke. The main elements of the swimming stroke lead to forward motion.

The mandible (Figures 1.5A, B) consists of well-developed coxale and basal segments. The distal end of the coxale has three parallel rows of teeth: the pars incisiva, the distal tooth list and a narrower proximal tooth list. The form of these tooth lists, and the number and type of teeth on the basal endite are genus specific. The number and type of setae on the exopodite and the length of the terminal setae on the basale are also morphologically significant taxonomic features. The mandible has complex musculature allowing the animal to perform strong biting and grinding action as well as to use the endopodite to manipulate food particles into the mouth.

The maxillae (Figure 5.1 C) are comparatively short with powerful musculature. Each one consists of a protopodite and a two-jointed endopodite. The protopodite points forward and outward, the first joint of the endopodite points downward and the end joint of the endopodite points backwards. The first endopodite segment bears a series of long, pointed setae anteriorly and three or four short pointed setae posteriorly. The second endopodite segment bears terminal claw setae. The maxillae are not sexually dimorphic and only vary slightly between genera. The maxillae have the essential role of sweeping the food onto the gnathobases of the mandibles.

The fifth limb (Figure 1.5D) consists of the basale, and a two-segmented endopodite. The ventral edge of the basale bears three plus two plus one plumose setae, three setae laterally and one long dorsal seta. The dorsal seta being a remnant of the exopodite and the ventral and lateral setae vary amongst the different genera. The first endopodite segment bears two ventral setae and one dorsal seta, and there are three terminal claw setae on the second segment, the central one being the longest. The fifth limb exhibits little sexual dimorphism and the limb assists with the manipulation of food items.

The sixth limb (Figure 1.6) consists of a basale with typically five ventral setae, three lateral setae and one dorsal seta, and a three-segmented endopodite. The first endopodite segment has one ventral seta, the second segment has one ventral and one dorsal setae. The terminal segment has three setae which are sexually dimorphic in most genera. In females (Figure 1.6A) the three terminal setae are relatively short and of differing lengths, but in the male (Figure 1.6B) Conchoeciinae and Euconchoeciinae the terminal three setae are subequal, very long and have fine hairs. These setae curve dorsally to project out between the carapace valves close to its posterior dorsal corner where, in males, there is a group of glands on each valve, whose secretions will be deposited on the long hairs on the setae.

The caudal furca (Figure 1.6C) is not sexually dimorphic and consists of a plate bearing seven or eight pairs of claws that diminish in size dorsally. The posterior claws point slightly backwards and all have spinules along the trailing edge. The caudal furca helps with manipulating large food particles and also has a cleaning function. The first stage juveniles have just two pairs of claws, and an additional pair is added at each of the six maturation moults.

The intromittent organ (Figure 1.6C) of the male is large, unilateral and positioned to one side of the carapace.

All of the limbs provide at least some characters of taxonomic significance, although limbs such as the first and second antennae have traditionally provided the most used characters.

1.3 Life Cycle

There have been very few studies on the life cycle of halocyprid ostracods, although Tseng (1975) carried out some experimental investigations on *Euconchoecia elongata* Tseng 1969, which belongs to an unusual genus within the halocyprid ostracods since the females brood their eggs, rather than releasing the clutches of eggs directly into the water (Angel 1979). Tseng (1975) sorted live specimens of *Euconchoecia elongata* from samples collected from the waters surrounding Guam in the west Pacific Ocean and transferred them to the laboratory. Eggs and embryos were removed from brooding females and kept on culture slides in filtered sea water. Once hatched the embryos were transferred to large beakers that contained lightly aerated, unfiltered seawater and fed on dead brine shrimp nauplii and copepods. They were kept under observation until they attained the adult stage. Hatching occurred at night or early in the morning and the metanauplius (Instar I) was oval in shape, possessed first and second antennae, mandible and had just two claws on the caudal furca. The maxillae and a third claw on the caudal furca appeared after the first moult (Instar II); the second moult produced the fifth limb and a fourth claw on the caudal furca (Instar III); during the third moult the sixth limb appeared and a fifth claw on the caudal furca (Instar IV). The fourth moult (Instar V) led to the appearance of the seventh limb and a sixth claw on the caudal furca. The ovaries appeared on the fifth moult with a seventh claw on the caudal furca (Instar VI) and the genitalia appeared on the sixth moult with an eighth claw on the caudal furca (Instar VII). Tseng (1975) found that Instars I, II and III lived 0.6 - 0.7 days, 1.5 – 2 days and 2 - 2.5 days respectively at 27 - 28° C, and that the total development time from Instar I to adult was 12 – 16 days.

Female halocyprid ostracods have been observed to store sperm at the base of the oviduct and it has been inferred that many clutches of eggs may be produced following a single mating (Angel 1979). However, no direct evaluation of fecundity is feasible, since it is not known how many clutches a female can produce or how frequently. Angel (1979) investigated the effect of a number of ecological parameters on clutch size and noted that deeper-living species tended to produce smaller clutches of large-sized eggs. He hypothesized that planktonic ostracods are long-lived, with relatively small clutch sizes, and that each female probably produces a number of clutches.

Ikeda (1992) collected samples of the halocyprid *Disconchoecia pseudodiscophora* Rudjakov, 1962 from a depth of 300 – 500 m in Toyama Bay, southern Japan in June and September 1990. Live animals were kept at in situ temperatures of 0° C and maintained on a diet of frozen and freshly killed copepods. All 12 females caught in June spawned, whilst only 6 of the 14 females captured in September spawned. It was also noted that the June-captured females survived in the laboratory for a mean of 130 days, whilst those caught in September survived for a mean of 53 days. The number of eggs released per brood varied from 1 – 10, and the mean brood size was 5.9 eggs (± 2.1 SD). The time between successive broods varied markedly from 2 – 64 days, with a mean of 31.0 days (±14.3 SD). The eggs hatched after 12 – 15 days into Instar I, in which two pairs of claws were present on the caudal furca. This was presumed to be a non-feeding stage as the mandible, maxillae and fifth limb were rudimentary and non-functional. Instar II developed after 33 days and, although the number of setae on the caudal furca remained the same the appendages were more developed, however, they were too undeveloped to suggest that the instar was able to feed. Instar III formed after 40 days with a full quota of functional appendages apart from the seventh limb. Stomach contents were apparent at this stage suggesting that feeding had commenced. Instar IV was not obtained in this experiment, so the duration of Instar III was uncertain.

During the study four separate broods were produced by one adult female with an interval of about 31 days between broods. If such a female produced 10 offspring per brood then the maximum potential fecundity would be 65. Results from the *Disconchoecia pseudodiscophora* experiments suggest that this species has a total of eight instars (seven juvenile stages and one adult). Since the adult females in this study survived for a maximum of 202 days the (Ikeda 1992) hypothesized that adult females of *D. pseudodiscophora* may live for up to 2 years.

Ikeda and Imamura (1992) examined the breeding season, development time of each instar, and life span of *Disconchoecia pseudodiscophora* from material collected over one full year from Toyama Bay in the southern Japan Sea during 1990. Their results showed the highest percentage of gravid females between April – July and lowest during September - December, indicating year round breeding, with a reproductive maximum in spring – summer. Instars I and II could not be studied as these were too small to be caught by the net of mesh size 0.10 mm. The greatest numbers of Instar III appeared in November – December 1990 and were presumed to originate from the breeding activity of females spawning in April – July 1990. Instar IV was most abundant in February 1990. These would have been spawned in 1989, developing to Instar V by June, and to Instar VI by September 1990. Development time from spawned eggs to adulthood, using both laboratory and field data, was estimated to be about 30 months at the ambient temperature of 0.5° C, with a generation time of 37 months for adult females and 33 months for adult males. In comparison with the results from *Euconchoecia elongata* with a development time of 12 – 16 days from Instar I to adult, *D. pseudodiscophora* appears to be very slow growing. However, the ambient water temperature from where the *D. pseudodiscophora* was collected was 0.5° C, whereas *Euconchoecia elongata* was collected from subtropical/tropical waters at

27° C. It has also been noted that non-pelagic benthic ostracods may take 3 – 5 years to develop from egg to adult in waters around 12° C off Sweden (Elofson 1941).

Blachowiak-Samolyk and Angel (2007) studied population assemblages for three species of halocyprid ostracod, *Alacia belgicae* Müller, 1906, *Alacia hettacra* Müller, 1906 and *Metaconchoecia isocheira* Müller, 1906 from Admiralty Bay, in the Southern Ocean, from February 1993 to January 1994. Samples were taken once every three weeks from two stations, the central part of Admiralty Bay, and the opening from the Bay into the Bransfield Strait, using a WP-2 net, which was of $0.196m^2$ and a mesh of 200µm. Results showed that the population of *A. belgicae* was dominated by A-3 instars during autumn, winter and spring, but by A-2 to adults during the summer suggesting it reproduces throughout the year. The *A. hettacra* population in autumn at both stations was 50% A-2 females, but by winter had increased to 75% at station A and 70% at station B. In spring only A-1 and adults were found at station A. The species was completely absent from station B. During the summer only the A-3 to adult stages were present at station B. From these results Blachowiak-Samolyk and Angel (2007) suggested that *A. hettacra* completes its life cycle within a year, with a new generation spawned in summer. *Metachonchoecia isocheira* adult females dominated the samples throughout all seasons at both stations. However, in the Admiralty Bay samples the numbers of A- 4 and A-3 stage instars increased in autumn-winter suggesting that *M. isocheira* reproduces during the summer and therefore completes its life cycle within one year.

1.4. The Oceanographic Environment of the Arabian Sea

1.4.1 Southwest and Northeast Monsoons

The Arabian Sea, to the northwest Indian Ocean, is bordered on the northern, eastern and western sides by the land masses of Asia and Africa. This profoundly affects the physical processes in the Arabian Sea leading to intense seasonal activity of atmospheric forcing of the northeast monsoon and southwest monsoon, with two intermonsoon periods. The upper layers of the water column are subject to extreme physical, chemical and biological shifts (Morrison et al. 1998). The southwest monsoon (August – September) is the most dynamic, producing persistent wind speeds of more than 30 knots. During the northeast monsoon (December – February) the winds though persistent are much lighter (Naqvi et al. 2003). During the southwest Monsoon the winds result in upwelling off the Gulf of Oman which leads to exceptionally high primary production in the surface waters (Rixen and Ittekkot 2005, Naqvi et al. 2010), resulting in extreme oxygen depletion in the subsurface waters. The subsequent northeast monsoon results from the air over the Asian land mass cooling quicker than the surface water of the ocean, which together with the Coriolis force, generates northeast winds over the Gulf. Surface evaporation greatly exceeds precipitation and in the absence of significant runoff from the land surface salinity rises substantially increasing the density of the surface waters. This increase in density is supplemented by the cooling effect of the northeast winds and results in the dense surface waters sinking (Naqvi 2003), and together with the aftermath of the exceptionally high productivity during the southwest monsoon, the sinking of the surface water deepens the oxygen minimum layer to a depth of 1000 m or more (Morrison et al. 1999). The importance of this oxygen minimum zone in the global nitrogen cycle has been emphasized by Rixen and Ittekkot (2005) who suggest that the extensive oxygen minimum zone (OMZ) in the Arabian Sea may account for much of the world oceans' water-column denitrification. Therefore, the northern Arabian Sea may be seen as a prime location for the study of mesozooplanktonic control of surface phytoplankton; the transfer of aerosols to the sea surface and the reaction of the food web to the resulting increase in micronutrients; the organisms and processes of the oxygen minimum layer, since these may be acute markers of climate change (Smith and Madhupratap 2005**).**

1.5 Arabian Sea

Before the 1990s only three major expeditions had undertaken any zooplankton sampling in the Arabian Sea. These were the John Murray Expedition of 1933 – 1934, the major contribution of which was the discovery of the oxygen minimum zone. The International Indian Ocean Expedition of 1959 – 1965, and the Indian Ocean Experiment of 1979 (Smith and Madhupratap 2005). One of the main objectives of the International Indian Ocean Expedition was to study the qualitative and quantitative distribution of planktonic organisms. The results were largely compromised by the use of hexamine to neutralise the formalin used for preservation so the samples rapidly decalcified (Angel personal communication). Even so, a preliminary study of the distribution and abundance of planktonic ostracods in the upper 200 m was achieved by George (1969), using the Indian Ocean Standard Net samples. George (1969) analysed a series of 1223 vertical hauls from 200 m to the surface, collected during the southwest monsoon and the northeast monsoon. The ostracod data showed that the majority of species collected were of the halocyprid family, and were most abundant in the northern regions of the Arabian Sea during the northeast monsoon. The average number of ostracods per haul was between 4001 – 8000, whilst during the southwest monsoon numbers fell to between 2001 – 4000 per haul. Generally the taxonomy of planktonic ostracods in the Indian Ocean has been poorly researched, with only Cannon (1940) who reported 7 species of halocyprid ostracod and Leveau (1967) making any substantial contribution.

In 1994 during the southwest monsoon, across-slope relations between the biological populations, the euphotic zone and the oxygen minimum zone off the coast of Oman were studied by Herring et al. (1998). This intensive study was carried out during a 17 day period and examined the vertical distribution of the macroplankton and micronekton in relation to the oxygen minimum layer during the southwest monsoon. The sampling area was centred at 19° N 59°E and a series of horizontal tows with a multiple rectangular midwater trawl system (RMT1+8) was taken. This system incorporates three pairs of nets fished consecutively, each pair comprising one net with a mouth size of 1 m^2 mouth area and a 0.33 mm mesh (RMT1) and another with a $8m^2$ mouth area and a 4.5 mm mesh (RMT8) (Roe and Shale, 1979: Roe et al. (1980). Rough seas damaged the fine mesh of the RMT1, so the sampling was incomplete (Herring et al. 1998). However, only one deep and three near-surface samples contained large quantities of animals. The 50 – 100 m day samples from the RMT1 net contained mainly medusae, whilst the night samples contained mostly copepods, fish and euphausiids. The deep sample biomass consisted primarily of one species of large medusa. The samples from the RMT8 net contained similar animals. These results were interpreted as evidence that the oxygen minimum zone restricts the bathymetric range and abundance of most species, and those few species that did occur within the zone were physiologically adapted to the low oxygen levels.

In 1995 a multidisciplinary oceanographic and atmospheric study of the Arabian Sea was undertaken by the US Joint Global Ocean Flux Study (JGOFS) of the National Science Foundation and the Forced Upper Ocean Dynamics Project of the Office of Naval Research. Smith et al. (1998) carried out zooplankton sampling using a double 1–m^2 MOCNESS, a 0.25-m^2 MOCNESS and Bongo nets. The double MOCNESS had two 1-m^2 MOCNESS systems side by side, and carried 20 nets (Wiebe et al. 1985). The MOCNESS was designed to fish with a 1-m^2 net mouth area when towed at a 45° angle (Wiebe et al. 1976). A flow meter mounted in front of the net opening enabled the volume of water sampled to be calculated (Wiebe et al. 1985). The double MOCNESS was fitted with 153 µm mesh nets plus CTD and oxygen probes. Sampling depths were from 1000 m to the surface in 100 m, 50 m and 25 m depth horizons. The plankton samples were preserved in 4% buffered formaldehyde/seawater solution. Bongo nets were used for sampling the upper 200 m and the frames were 60 cm diameter and fitted with 153 µm and 335 µm mesh nets. The volume of water filtered was determined by the addition of flow meters in the net mouth openings. Morrison et al. (1999) measured the oxygen minimum zone (OMZ) throughout the year by recording values of dissolved oxygen, nitrite, nitrate, and density.

Results from the zooplankton sampling showed that the majority of species avoided the suboxic core of the oxygen minimum zone. Surprisingly high numbers of a few species that vertically migrated spent much of the daytime within the oxygen minimum zone. These were predominantly euphausiids and some species of myctophid fish that migrated to a maximum depth of 400 m by day returning to the well oxygenated surface waters at night to feed. The copepod *Calanoides carinatus* Kroyer, 1849 a seasonal migrant, was found at the lower limits of the oxygen minimum zone, albeit in a non-feeding diapausing stage, rising to the surface to feed and reproduce during the SW Monsoon (Smith et al. 1998). Madhupratap et al. (2001) reported that south of 15°N copepods were the most abundant zooplankton, however, further north ostracods became equally abundant. Copepods and ostracods contributed 85% of the total zooplankton biomass, with chaetognaths, euphausiids, siphonophores and tunicates making up the bulk of the remaining 15%. Below the suboxic layer there was zooplankton biomass increase and zooplankton feeding rates increased (Naqvi 2003).

Wishner et al. (1998) found the food chains in this layer were short and the particulate organic carbon (POC) was used up more readily than in the overlying suboxic layer. However, study of the northeastern Arabian Sea has been incomplete since no data were taken within the Gulf of Oman (Morrison et al. 1999).

1.6 RRS *Charles Darwin* Cruise

During the northeast monsoon of 1997 the Scheherezade cruise took place. This was an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and the southern Arabian Gulf (Herring et al. 1998). During the cruise a series of horizontal tows was made with the multiple rectangular midwater trawl (RMT1+8) net system. A flowmeter was used to establish the volume filtered, and CTD and oxygen data were obtained close to Station 54001 (24°N 58°E) (Figure 1.7). The water column was sampled in 50 m, 100 m and 200 m depth zones to a depth of 2000 m. Most tows were of 1 h duration and a separate series of day and night samples was taken at each depth to discover the extent of diurnal vertical migration. The CTD and oxygen data showed the extreme oxygen minimum layer to be between 90 m and 1000 m. The biomass of each preserved sample was measured. Biomass was found to decrease sharply, correlating with the measured oxygen minimum layer.

From 200 – 1000 m the vertical distribution and abundance of the dominant species of fish, decapod shrimps and siphonophores were analysed from the Scheherezade cruise (Herring et al 1999) to ascertain which groups of animals might contribute to the observed acoustic backscatter. Fish, decapod shrimp and siphonophores were sorted from the RMT8 samples from Station 54001 and identified, counted and measured. A total of 38 species of fish, 21 species of shrimp and 43 species of siphonophore were identified. The resulting distribution patterns help identify those species that can cope with the low oxygen levels in the water column and, when present, they usually occur in very high numbers. In midwater the myctophid and gonostomatid fishes and decapod shrimps make a significant contribution to acoustic backscatter and, at the surface, siphonophores are present in sufficient numbers to add to near-surface backscatter. The samples taken by the RMT1 nets were only assessed for biomass and had not been sorted into groups.

1.7 Present Research

This project has examined the halocyprids collected in the RMT1 samples during the Scheherezade cruise. It has focused primarily on resolving the taxonomic problems presented by the complex taxonomy of the halocyprid ostracods in the Gulf of Oman. Particular attention was paid to the genus *Euconchoecia* because of its abundance in the samples, other taxonomic problems addressed include the separation of a new genus *Mamilloecia* from *Paraconchoecia*, establishing a new genus, *Huxleyoecia,* and addressing nomenclatural issues involving the genus *Mollicia* (*Mollicoecia*). The bathymetric profiles of the halocyprid species have been related to profiles of the abiotic parameters salinity, temperature and oxygen. The species composition and day/night distribution of halocyprid ostracods in the Gulf of Oman samples are analysed, and the data compared with similar results from 30ºN in the Atlantic where there is no extreme oxygen minimum zone.

1.8 Figures

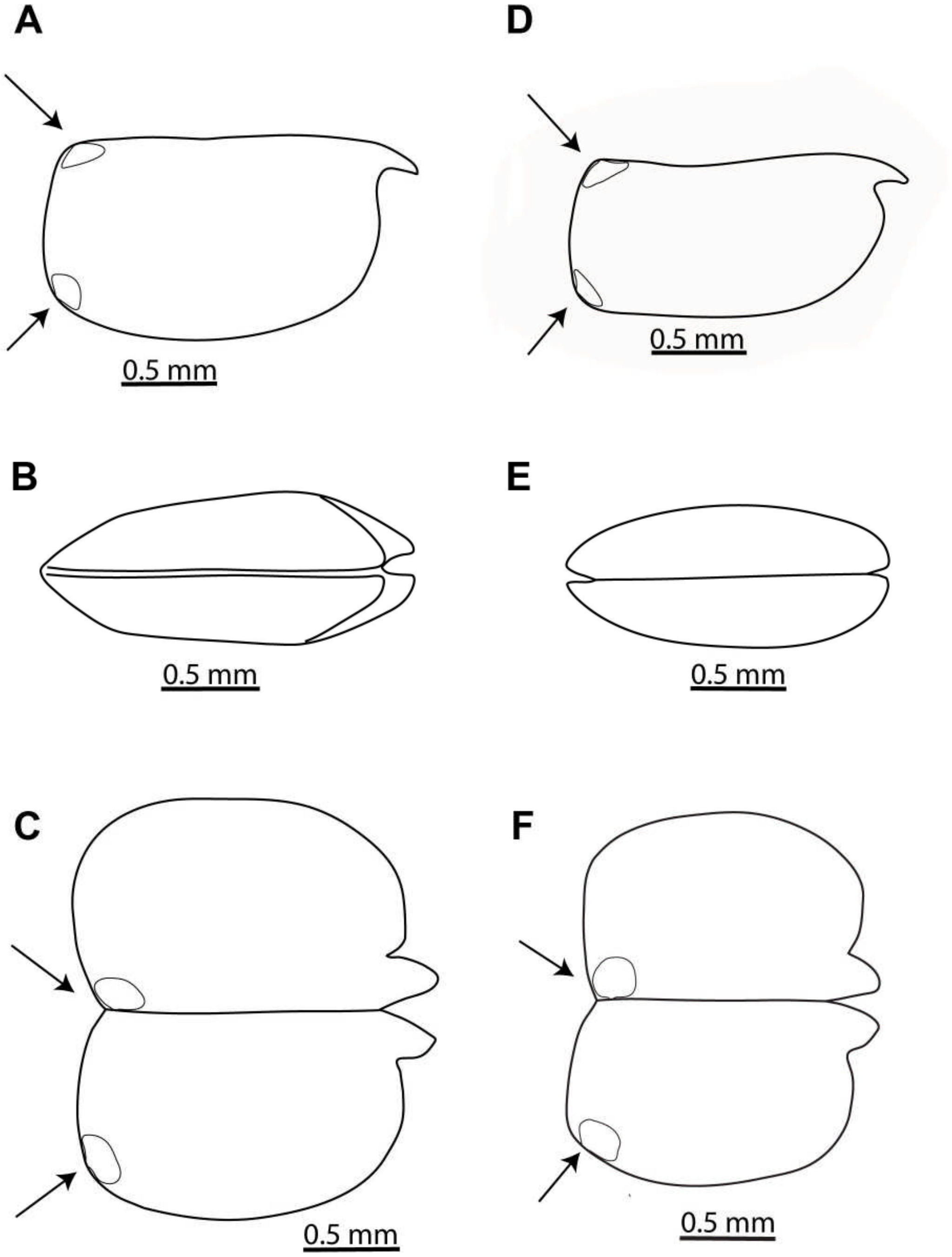


Figure 1.1. Halocyprid ostracod, arrows indicate asymmetric glands (A) female lateral view, (B) female ventral view, (C) female carapace dissected and viewed dorsally, (D) male lateral view, (E) male ventral view, (F) male carapace dissected and viewed dorsally.

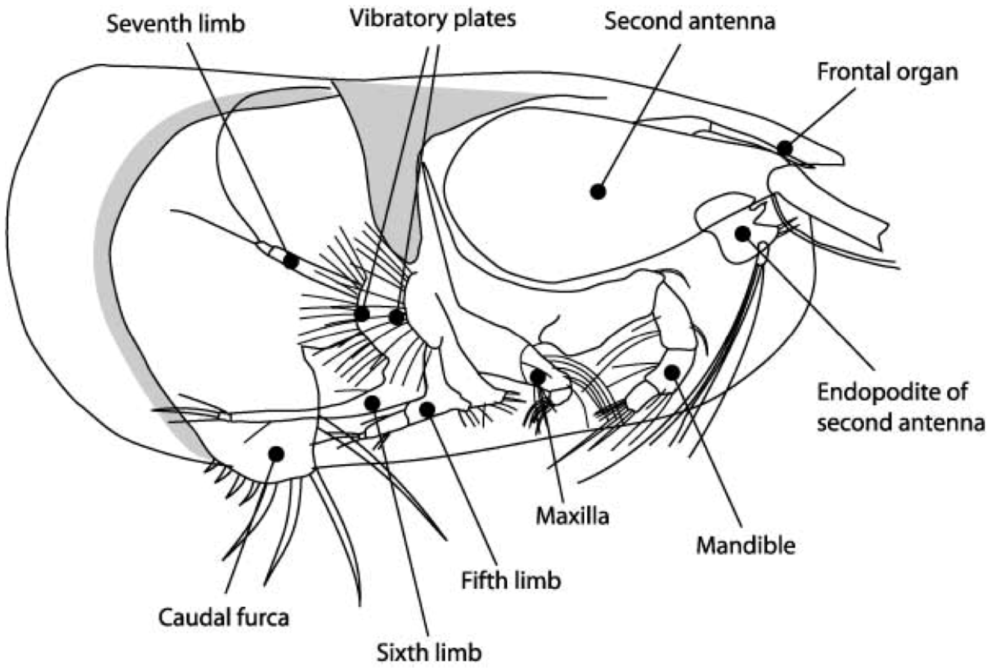


Figure 1.2. Position of limbs inside carapace (after Iles 1961.).

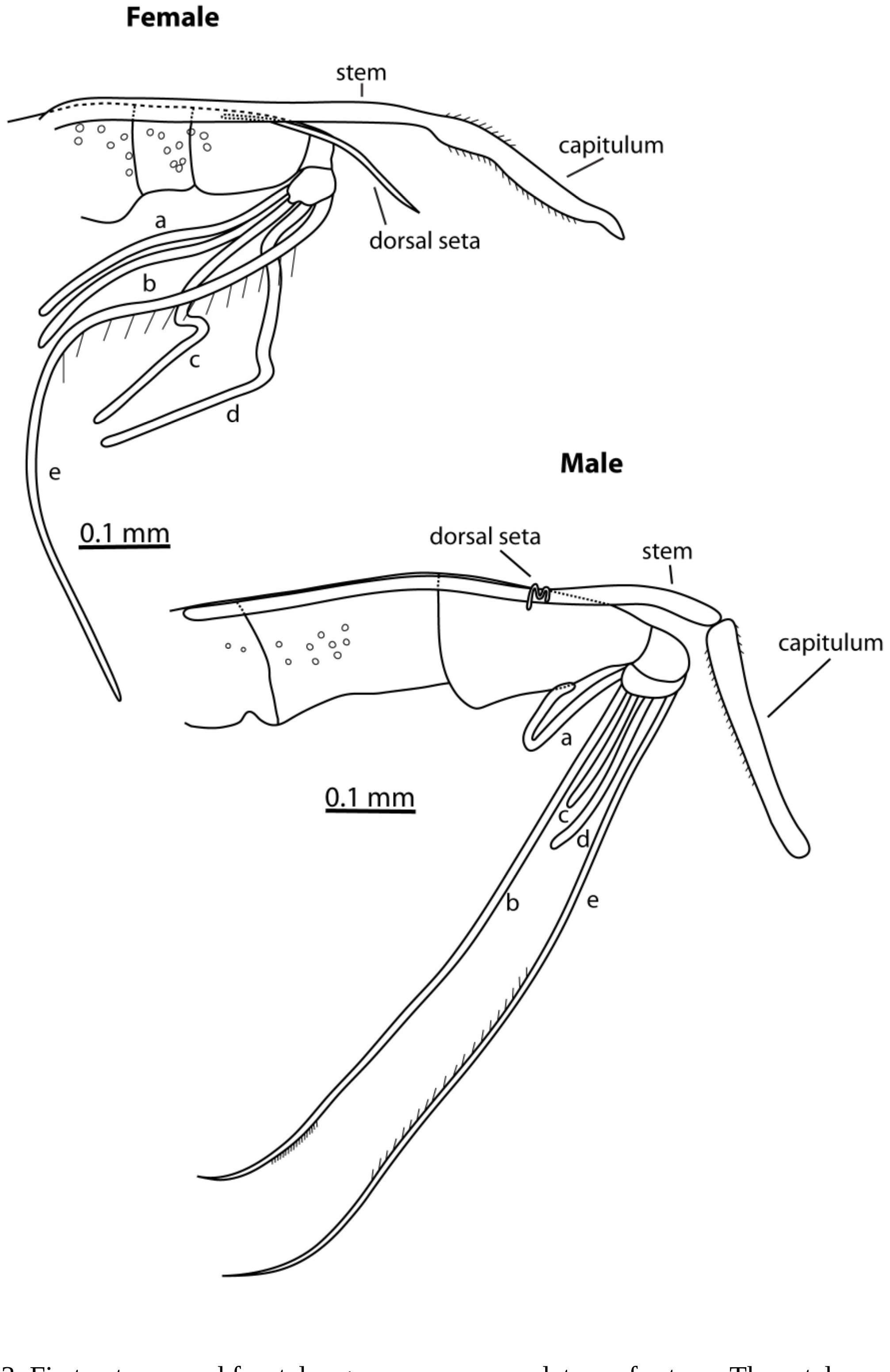


Figure 1.3. First antenna and frontal organ, a – e nomenclature of setae. . The setal nomenclature for the first antenna is based on Skogsberg (1920) and Iles (1951), and is now used universally in halocyprid taxonomy.

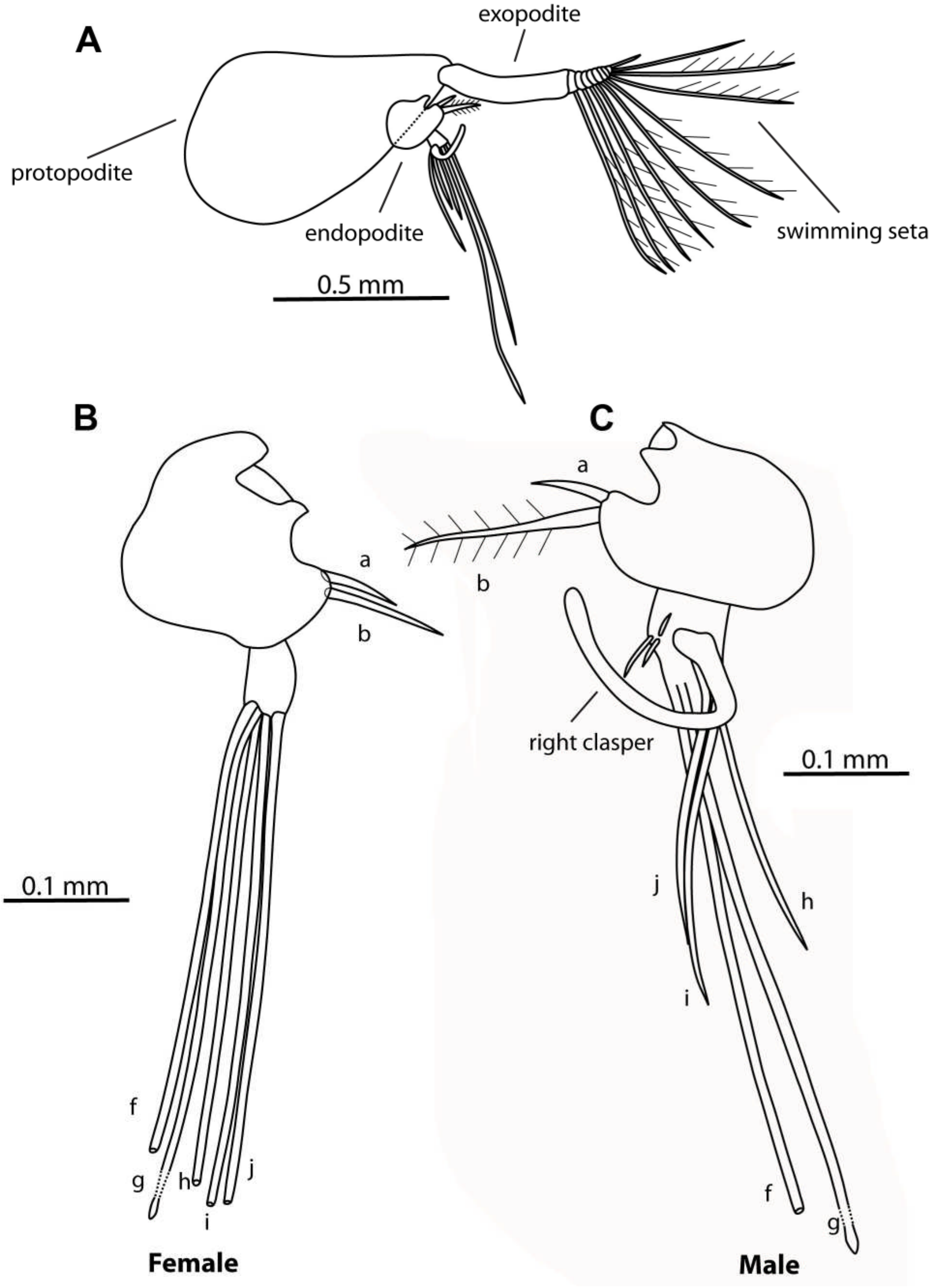


Figure 1.4. (A) second antenna, (B) female endopodite, a, b, f- i nomenclature of setae, (C) male right endopodite, a, b, f- i nomenclature of setae.

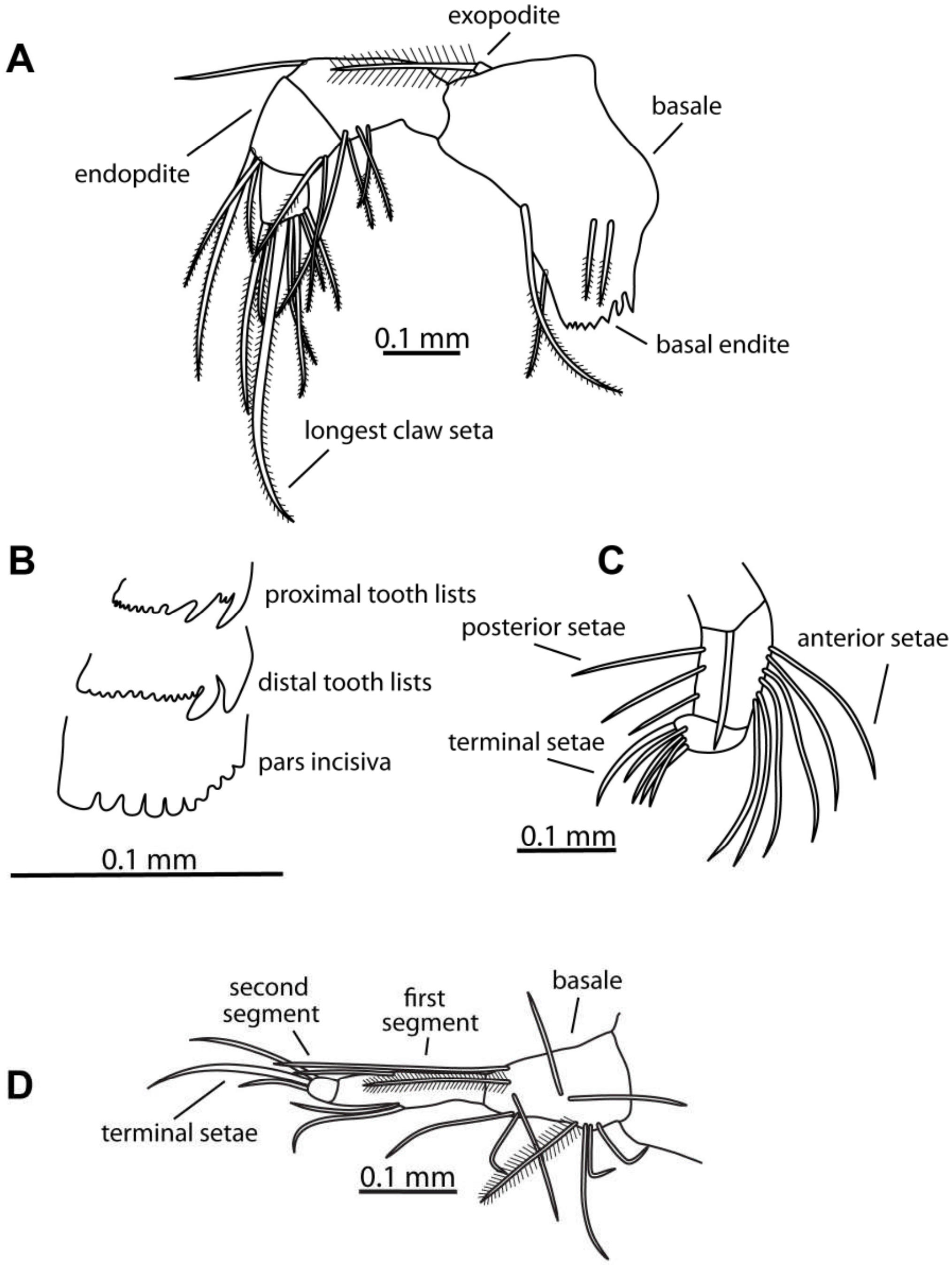


Figure 1.5. (A) mandible, (B) tooth lists of the coxale, (C) maxilla, (D) fifth limb.

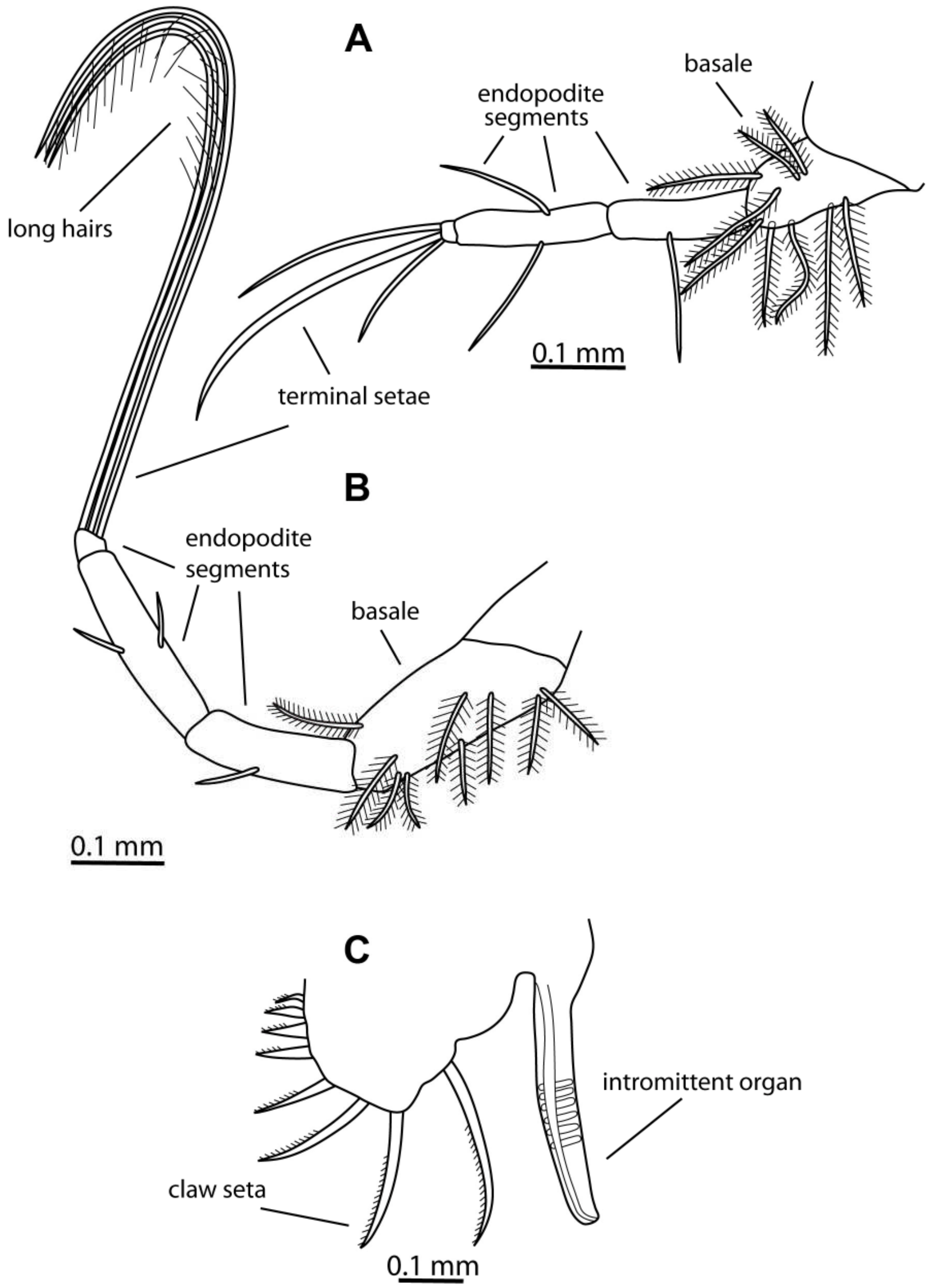


Figure 1.6. (A) female sixth limb, (B) male sixth limb (C) male caudal furca and intromittent organ.

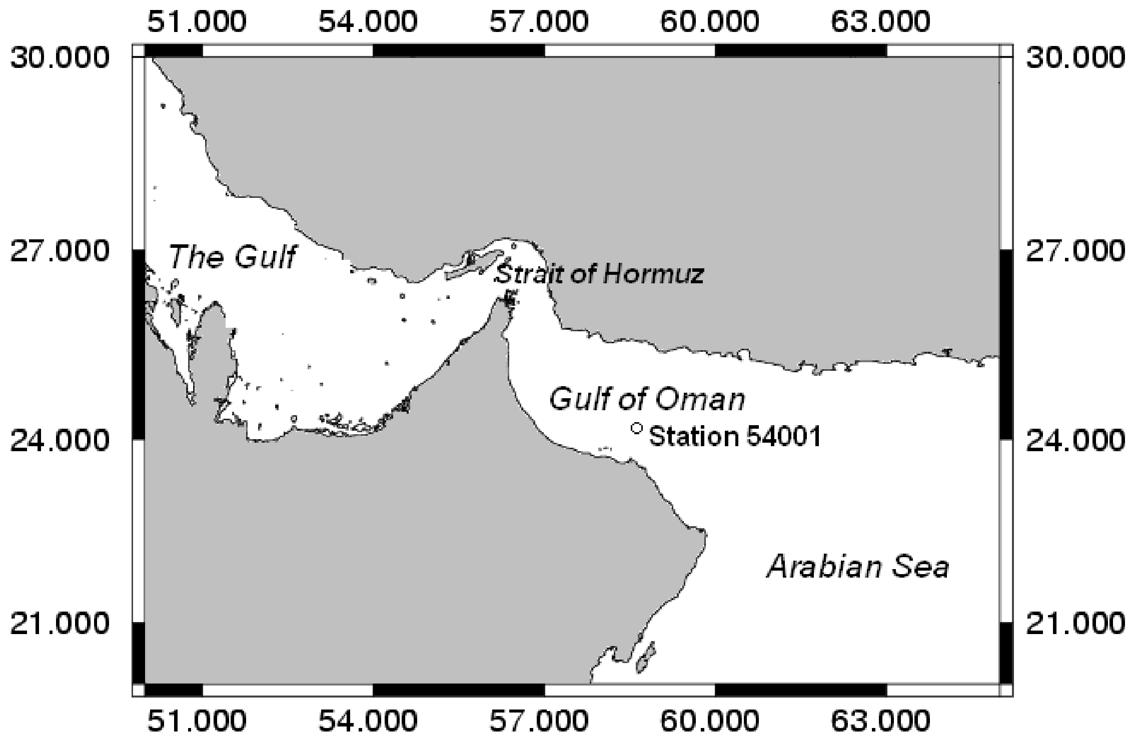


Figure 1.7. Gulf of Oman showing position of Station 54001.

1.9 References

Angel MV. 1979. Studies on Atlantic halocyprid ostracods: their vertical distributions and community structure in the central gyre region along latitude 30° N from off Africa to Bermuda. Progress in Oceanography, 8, 1 – 122.

Angel MV. Blachowiak-Samolyk K. Drapun I. Castillo R. 2007. Changes in the composition of planktonic ostracod populations across a range of latitudes in the North-east Atlantic. Progress in Oceanography, 73, 1, 60-78.

Blachowiak-Samolyk K**.** Angel M.V. (2007) A year round comparative studies on the population structures of pelagic Ostracoda in the Admiralty Bay (Southern Ocean). Hydrobiologia , 585, 67-77.

Brady GS. 1880. Report on the Ostracoda dredged by H.M.S. Challenger during the years 1873 – 1876. Scientific Results of the Voyages of H.M.S. Challenger (Zoology). 1 (3), 1 – 184.

Cannon HG. 1940. Ostracoda. Reports of the John Murray Expedition 1933 – 1934, 6, 319 – 325.

Chavtur VG. 2003. Morphology and distribution of some new pelagic ostracods of genus *Metaconchoecia* (Halocyprida: Halocyprididae) from the North Pacific. Zootaxa, 229, 1 – 102.

Chavtur VG. Stovbun GG. 2003. Revision of pelagic ostracods of the subfamily *Archiconchoecinae*. Publications of the Seto Marine Biological Laboratory, 39, 139 – 219.

Claus C. 1874. Die Familie der Halocypriden. Schriften zoologischen Inhalts, 1, 4-16.

Claus C. 1891. Die Halocypriden des Atlantisches Oceans und Mittelmeres. Alfred Hölder, Wien, 1–81.

Dana, JD. 1849. Conspectus Crustaceorum quae Orbis Terrarum circumnavigatione, Carolo Wilkes e Classe Republicae Foederatae Duce, lexit et descripsit J.D. Dana. Proceedings of the American Academy of Arts and Sciences, 2, 9061.

Dana J.D. 1852. Crustacea. Part II. In: United States Exploring Expedition During the Years 1838, 1839, 1840, 1841, 1842 Under the Command of Charles Wilkes, U.S.N., 13, (2), 689-1618.

Deevey GB. 1968. Pelagic ostracods of the Sargasso Sea off Bermuda. Bulletin of the Peabody Museum of Natural History, 26, 1-125.

Elofson O. 1941. Zur kenntnis der marinen Ostracoden Schwedens, mit besonderer berucksichtigung des skagerrads, Zoologiska Bidrag fran Uppsala, 19, 215-534

George J. 1969. A preliminary report on the distribution and abundance of planktonic ostracods in the Indian Ocean. Bulletin of the National Institute of Science India, 38, 641 – 648.

Herring PJ. Howell PR. Roe HSJ. 1998. Scheherezade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb – 30 Apr 1997. No11. Biomass data. Leg 1, 12 Feb – 19 Mar 1997 (Unpublished manuscript).

Herring PJ. Howell PR. Pugh PR. 1999. Scheherezade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb – 30 Apr 1997. No 16, Fish, decapod shrimps and siphonophores: abundances and size data. Leg1. 12 Feb – Mar 1997 (Unpublished manuscript).

Ikeda T. 1992. Laboratory observations on spawning, fecundity and early development of a mesopelogic ostracod, *Conchoecia pseudodiscophora*, from the Japan Sea. Marine Biology, 113, 313 – 318.

Ikeda T. Imamura A. 1992. Population structure and life cycle of the mesopelagic ostracod *Conchoecia pseudodiscophora* in Toyama Bay, South Japan, Marine Biology, 113, 595 – 601.

Iles EJ. 1961. The appendages of Halocypridae. Discovery Report, 31, 299 – 326

Leveau, M. 1967. Ostracodes pélagique du sud-ouest de l’Océan Indien (Région de Tuléar). Recueil des travaux de la Station Marine d’Endoumme-Marseille (Fax. hors. série. suppl.), 6, 63 – 70.

Madhupratap M. Gopalakrishnan TC. Haridas P. Nair K.C. 2001. Mesozooplankton biomass, composition and distribution in the Arabian Sea during the fall intermonsoon: Implications of oxygen gradients. Deep Sea Research II, 48, 1345 – 1368.

Morrison JM. Codispoti LA., Gaurin S. Jones, B. Magnhnani V. Zheng Z. 1998. Seasonal variation of hydrographic and nutrient fields during the US JGOFS Arabian Sea Process Study. Deep Sea Research II, 45, 2053 – 2102.

Morrison JM. Codispoti LA. Sharon L. Wishner K. Flagg C. Gardner WD. Gaurin S. Naqvi SWA. Magnhnani V. Prosperie L. Gundersen JS. 1999. The oxygen minimum zone in the Arabian Sea during 1995. Deep Sea Research.Part II : 46, 1903 – 1931.

Müller G.W. 1890. Ueber Halocypriden. Zoologische Jahrbücher, 5, 253-280.

Müller G.W. 1894. Die Ostracoden des Golfes von Neapel und der angrezenden Meeres-Abschnitte. Fauna Flora Golf. Neapel, 21, 1-104.

Müller GW. 1906. Ostracoda. Wissenschaftliche Ergebnisse der Deutschen Tiefsee-Expedition *‘Valdivia’* 1989 – 1899, 8, 29 – 154.

Müller GW. 1912. Ostracoden. Das Tierreich, 31, 1–434.

Naqvi SWA. Naik H. Narvekar PV. 2003. The Arabian Sea. In: Biogeochemistry of Marine Systems, Ed: K. Black and G. Shimmield, Biological Sciences Series, Ch 6, 157 – 207.

Naqvi SWA. Moffet JW. Gauns MU. Narvekar PV. Pratihary AK. Naik H. Shenoy DM. Jayakumar DA. Goepfert TJ. Patra PK. Al-Azri A. Ahmed SI. 2010. The Arabian Sea as a high-nutrient, low-chlorophyll region during the late Southwest Monsoon, Biogeosciences, 7, 2091 – 2100.

Poulsen EM. 1969. Ostracoda-Myodocopa. 3a. Halocypriformes-Thaumatocypridae and Halocypridae. *Dana Report*, **75**, 1 – 100.

Rixen T. Ittekkot V. 2005. Nitrogen deficits in the Arabian Sea, implications from a three component mixing analysis, Deep Sea Research II 52 (2005) 1879 – 1891.

Roe HSJ. Shale DM. 1979. A new multiple rectangular midwater trawl (RMT1+8) and some modifications to the Institute of Oceanographic Sciences’ RMT1+8, Marine Biology, 50, 283 – 288.

Roe HSJ. Baker AdeC. Carson RM. Wild RA. Shale DM. 1980. Behaviour of the Institute of Oceanographic Sciences’ rectangular midwater trawls; theoretical aspects and experimental observations, Marine Biology, 56, 247 – 259.

Skogsberg T. 1920. Studies on marine ostracods. Part 1. (Cypridinids, halocyprids and polycopids). Zoologiska Bidrag Fran Uppsala, Supplement 1, 1–784.

Smith S. Roman M. Wishner K. Gowing M. Codispoti L. Barber R. Marra J. Prusova I. Flagg C. 1998. Seasonal response of zooplankton to monsoonal reversals in the Arabian Sea, Deep Sea Research II, 45, 2369 – 2404.

Smith S.L. Madhupratap M. 2005. Mesoplankton of the Arabian Sea: Patterns influenced by seasons, upwelling and oxygen concentrations, Progress in Oceanography, 65, 214 – 239.

Tseng WY. 1975. Biology of the pelagic ostracod, *Euconchoecia elongata* Müller, Reports of the Taiwan Laboratory of Fish Biology, 27, 1 – 183.

Wiebe P. Burt K. Boyd S. Morton A. 1976. A multiple opening/closing net and environmental sensing system for sampling zooplankton, Journal of Marine Research, 34, 313 – 326.

Wiebe P. Morton A. Bradley A. Backus A. Craddock J. Barber V. Cowles T. Flierl G. 1985. New developments in the MOCNESS, an apparatus for sampling zooplankton and micronekton, Marine Biology, 87, 313 – 323.

Wishner K.J. Gowing M.M. Gelfman C. 1998. Mesozooplankton biomass in the upper 100m in the Arabian Sea: Overall seasonal and geographic patterns and relationship to oxygen gradients, Deep Sea Research, II, 45, 2405 – 2432.

Chapter 2 **(Published as Graves, C (2011) J. Nat. Hist. 45: 1937-1981)**

Redescription of *Euconchoecia chierchiae* Müller, 1890 and *Euconchoecia aculeata* (Scott, 1894) (Halocyprididae, Ostracoda) from the Atlantic, and Descriptions of Two Novel Species of *Euconchoecia* Müller 1890, from the Gulf of Oman

2.1 Abstract

The 100 – 0 m samples from a stratified zooplankton sample series from the upwelling region of the Gulf of Oman, during February 1997, were numerically dominated by members of the poorly known halocyprid genus *Euconchoecia*. A modern diagnosis of the genus *Euconchoecia* is provided and the type species, *E. chierchiae* (Müller, 1890) from the Atlantic is redescribed. A second species from the Atlantic, *E. aculeata* (Scott, 1894) is also redescribed. In the Gulf of Oman samples there are two size groups, and these were previously identified as *Euconchoecia chierchiae* and *E. aculeata*. However, when compared with specimens from the Atlantic and with published descriptions of these two species, the Gulf of Oman specimens could not be assigned to any previously described species. In this chapter the Gulf of Oman species are described as new species, *Euconchoecia omanensis* and *Euconchoecia hormuzensis*, and are compared in detail with the redescriptions of the Atlantic species, *E. chierchiae and E. aculeata*.

2.2 Introduction

When analysing *Discovery* station 54001, at 24º 12' N, 58º 40' E, a series of stratified zooplankton samples from the upwelling region of the Gulf of Oman, the 100 – 0 m samples were found to be numerically dominated by members of the poorly known halocyprid genus *Euconchoecia,* together with a species of the myodocopid genus *Cypridina* Edwards, 1840. The genus *Euconchoecia* is exceptional amongst halocyprid ostracods in that the females retain their eggs in a brood pouch within the carapace, releasing them at the first juvenile instar stage. There are two size groups in the Gulf of Oman samples, and these were previously identified as *Euconchoecia chierchiae* and *E. aculeata* by George (1977). However, when compared with material from the Atlantic and with published descriptions of these two named species, the Gulf of Oman specimens could not be assigned to either. In this chapter the two Atlantic species are fully redescribed: *Euconchoecia chierchiae,* based on material collected off Bermuda at *Discovery* station 8281 in 1973, and *Euconchoecia aculeata* (Scott, 1894) based on the type material collected during the cruise of the Telegraph Steamer the *Buccaneer* in 1893. Detailed comparisons of the Gulf of Oman specimens with the new descriptions of the Atlantic species were made. The Gulf material represents two new species which are also described in detail.

The genus *Euconchoecia* was established by Müller (1890) as a monotypic genus based on males of *Euconchoecia chierchiae,* the type species, which had been collected in neritic waters off the Coast of Brazil. According to Skogsberg (1920) Cleve subsequently collected two more male specimens from the North Atlantic, but identified them as *Paraconchoecia oblonga* (Cleve, 1900). Since Cleve gave neither a full description nor any figures, this identification is dubious, although both his specimens displayed the spine at the posterior dorsal corner of the carapace that is characteristic of

Euconchoecia. *Euconchoecia chierchiae* was next reported by Brady (1902) from Cruz Bay, St John, Virgin Islands, but his rather sketchy description differs from Müller's (1906) later account, so doubt also remains as to the correctness of his identification. Müller (1906) described the female and redescribed the male from the Brazilian coast, but by modern standards his description and his illustrations are inadequate. Skogsberg (1920) provided the first detailed description of both sexes, collected from oceanic waters off Brazil. His material came from close to the type locality, but his description and figures deviate from Müller's (1906). Vavra (1906) also reported *E. chierchiae* from the Atlantic but all his descriptions are poor. Tseng (1969), working on samples from the Taiwan Strait, published the first report of *E. chierchiae* from outside the Atlantic. His descriptions and drawings again deviate significantly from Müller's (1906) descriptions. Poulsen (1969) reported both *E. chierchiae* and *E. aculeata* from numerous Dana stations in the Atlantic, Pacific and Indian Oceans and suggested that the first antenna of the male may have seven segments, two more than originally described by Müller (1890, 1906), but the last two segments were often difficult to observe. There has, thus, been considerable confusion surrounding the identity of the type species of the genus, *Euconchoecia chierchiae.*

A number of other species of *Euconchoecia* have been described from Chinese seas, namely *Euconchoecia maimai* (Tseng, 1969), *Euconchoecia shenghwai* (Tseng, 1969), *Euconchoecia elongata* (Tseng, 1969), *Euconchoecia pacifica* (Chavtur, 1976) and *Euconchoecia bifurcata* (Chen and Lin, 1984). Thus *Euconchoecia* species have been reported from the Atlantic, Pacific and Indian Oceans, but always restricted to tropical and sub-tropical latitudes between 40º N and 40º S, and predominantly in the upper 50m of the water column. Abundances are greatest 'in neritic waters with an oceanic effect' (da Rocha 1983).

Seven species, including the type species *Euconchoecia chierchiae chierchiae*, Müller 1890, and two subspecies of *Euconchoecia* have been described to date:

Euconchoecia chierchiae chierchiae Müller, 1890

Euconchoecia chierchiae aspicula (Deevey, 1970)

Euconchoecia aculeata (Scott, 1894)

Euconchoecia bifurcata bifurcata Chen & Lin, 1984

Euconchoecia bifurcata pax Kornicker, 1989

Euconchoecia elongata (Müller, 1906)

Euconchoecia maimai Tseng, 1969

Euconchoecia pacifica (Chavtur, 1976)

Euconchoecia shenghwai Tseng, 1969

Chavtur and Stovbun (pers. com) consider that the genus should comprise sixteen species, raising *Euconchoecia chierchiae aspicula* and *Euconchoecia bifurcata pax* to full specific status, and reorganizing seven additional new species, which may have been misattributed as other known species. All the material cited by these authors was collected from the western coastal waters of the Pacific Ocean and they included *Euconchoecia chierchiae* in their study of the systematics of the genus *Euconchoecia.*

The second *Euconchoecia* species to be described was *Euconchoecia aculeata* (*S*cott, 1894) based on specimens collected from the Gulf of Guinea. Scott (1894) deposited type material in the Natural History Museum, London, attributing his species to the genus *Halocypris* (Dana, 1853), as *Halocypris aculeata.* Müller (1906, 1912) correctly re-assigned it to *Euconchoecia*. Both Poulsen (1969) and Tseng (1969) later reported this species from various locations outside the Atlantic but without re-examining the type material. Scott's original description was far too sketchy to be confident that these later reports were correctly assigned to his species. Both *E. chierchiae* and *E. aculeata* have been reported from the Indian Ocean (George 1977), but based on the illustrations, these identifications are misattributed and one of them was almost certainly one of the two novel species described below from the Gulf of Oman.

2.3 Materials and methods

The material described in this paper was from three sources:

1) The Atlantic material of *Euconchoecia chierchiae* collected in 1973 off Bermuda at *Discovery* Station 8281, 31º 55' 18" N, 63º 52' 0" W (Angel 1979), using the multiple rectangular midwater trawl net system (RMT1+8) (Roe and Shale 1979, Roe et al. 1980). The zooplankton samples were originally fixed in 5% seawater formalin and after being sorted were transferred to 70% ethanol for storage at the Natural History Museum, London.

2) The type material from the Atlantic of *E. aculeata* (Scott, 1894), was deposited in the Natural History Museum, London by Scott. The material was collected by a naturalist on board the Telegraph Steamer *Buccaneer* in 1893 at a station position of 0º 19' 2" S, 7º 19' 0" E. The type specimens, two females, two males and two juveniles, are now preserved in 80% ethanol.

3) Zooplankton samples collected in the Gulf of Oman in 1997 during the Northeast monsoon (Herring et al. 1998 and Herring et al. 1999). Stratified zooplankton samples were collected by day and by night at an oceanic station in the Gulf of Oman (Discovery 54001, 24° 12' N, 58° 40' E) using a multiple rectangular midwater trawl (RMT1+8) (Roe and Shale 1979, Roe et al. 1980). The mesh size of the zooplankton net (RMT1) was 320μm, so only adults would have been quantitatively sampled. Total zooplankton samples were initially fixed in 5% seawater formalin, and transferred after 24 h into Steadman’s preserving fluid (0.5% propylene phenoxetol, 4.5% propylene glycol, 5%

formalin seawater solution) before being stored for later analysis at the Natural History Museum, London. In 2006 the Steadman's preserving fluid was replaced by 80% ethanol and the planktonic ostracods were picked out and sorted to species. Specimens of *Euconchoecia* were exceptionally abundant (Table 2.1) in the wind-mixed layer (the upper 100 m) overlying the strong oxycline leading to a depth zone with almost no measurable oxygen that extended from 90 – 1200 m (Herring et al.1998).

Angel's 1973 Atlantic samples were re-examined: thirty two females and nine males of *Euconchoecia chierchiae* were measured. One adult of each sex was selected from the sorted material, placed on a cavity slide and stained with lignin pink dissolved in lactophenol for 15 min. The stained specimens were dissected using a stereoscopic microscope and mounted on microscope slides as temporary preparations in lactophenol.

The vial of the type material of *E. aculeata* contained four adults, two females and two males. The best condition female was selected as the lectotype and the best condition male as a paralectotype. Both specimens were clogged with detrital particles, which had accumulated over the century since they had been collected; at least some of this detritus probably resulted from when the specimens were first transferred into alcohol, if the salt water had not been fully washed out. This detrital material was successfully removed from these fragile specimens by briefly placing them in an ultrasonic bath. The specimens were measured, dissected and mounted in lactophenol, but without staining, since such old specimens do not take up stain.

Initial examination of adults from the Gulf of Oman showed there were two size groups of both males and females. It was suspected that there were two species, so large numbers of adult males and females of each size category were measured. The large females measured 1.42 ± 0.06 mm (n = 100), the small females 1.04 ± 0.05 mm (n =

48), the large males 1.15 ± 0.04 mm (n = 100) and the small males 1.00 ± 0.03 mm (n = 36). Selected individuals were stained with lignin pink dissolved in lactophenol for 15 min, then dissected in lactophenol on a cavity slide using a stereoscopic microscope. These slides were examined under an Olympus BH2 compound microscope using Nomarski illumination (differential interference contrast (DIC)). A standard set of measurements was made of the carapace, limbs and setae (see Angel and Blachowiak-Samolyk 2006). These measurements were standardised by expressing them as percentages of the individual carapace lengths. A camera lucida on the Olympus BH2 with DIC was used to make pencil drawings of both the complete animal and the individual dissected parts. These sketches were scanned and re-drawn using Adobe Illustrator and collated in Adobe Photoshop.

The nomenclature of Skogsberg (1920) for the structure and setae of the antennae, mandible, maxilla, 5th limb, 6th limb, 7th limbs and caudal furca has been used throughout. By convention males are described first, but as the *E. aculeata* male dissection was incomplete, the female is described first and to be consistent the females are described first for all species. On the first antenna of each specimen the detachment point varied between individuals, so accurate measurements of the first segment were not comparative, therefore only measurements for the other segments have been recorded.

2.4 Systematics

Class **Ostracoda** Latreille, 1802

Subclass **Myodocopa** Sars**,** 1866

Order **Halocyprida** Dana, 1853

Suborder **Halocypridina** Dana, 1853

Family **Halocyprididae** Dana, 1853

Subfamily **Euconchoecinae** Poulsen, 1969

Genus ***Euconchoecia*** Müller, 1890

2.5 Diagnosis of *Euconchoecia* Müller, 1980

Carapace usually smooth, lacking any sculpture, shape elongate, rostra well developed but asymmetrical; posterior dorsal corners usually pointed. The 'asymmetrical glands' open almost symmetrically just below posterior dorsal corner. Frontal organ long, extends beyond second segment of first antennae (Skogsberg 1920), but ± length of first antenna. First antennae (A1) show marked sexual dimorphism, in both sexes fourth segment bears ventrally more than twenty bundle setae of similar length and thickness. Terminal A1 segment bears four or five unarmed setae. In males two setae are long and powerful; the longest seta more than three times lengths of bundle sensory setae and 50% carapace length (CL). Protopodite of second antenna (A2) large and powerful. In males = 35 - 40% CL. A2 endopodite lacks any c-, d- and e-setae (that are typical of other halocyprids), f- and g-setae very long. The male right A2 endopodite with elongate hooked clasping organ, with long proximal shank with h-, i- and j-setae inserted distally, end piece long, curved. Left A2 endopodite has 'hook' reduced to just straight basal shank, also carries three setae terminally. Female A2 endopodite without c-, d- and e-setae, f- and g-setae shorter than in male. First segment with small verucca carrying a single seta (similar in length to i-seta of male). Coxale of mandibular protopodite is an elongate triangular structure that contains complex musculature that generates the biting action. Distal end of the coxale has three parallel rows of teeth: pars incisiva, distal tooth list, and narrower proximal tooth list. Basale with distal edge of sub-serrate teeth, one tubular tooth and one dagger-shaped tooth; laterally with four long setae and a plumose seta. The exopodite consists of a long plumose seta. The segmented endopodite with a short, bare dorsal seta sits on first segment plus three spinose ventral setae. Second segment with one spinose ventral seta and two dorsal spinose setae. Terminal segment with seven spinose setae; the longest almost as long as carapace. Basal segment of maxilla with five anterior, one lateral and four posterior setae. Distal segment short and wide with six claw setae, the posteriormost is longer than others, anterior seta with secondary spines, ornamented with short fine hairs. Ventral edge of basale of fifth limb with five spinose pointed setae, and laterally two plumose setae. First endopodite segment with two ventral setae and one dorsal seta; all spinose. Second segment with three curved unequal terminal claw setae; central claw is longest. Main axes of both fifth and sixth limbs in both sexes are endopodites, the dorsal seta on the basale is a remnant exopodite (see Boxshall 1998, Kornicker 2003). In females, basale of sixth limb with ventrally three spinose setae plus one plumose seta, laterally a plumose seta, dorsally a single seta. First endopodite segment with two ventral setae. Second segment with single spinose setae ventrally and dorsally. Terminal segment with three unequal serrate setae. Male sixth limb differs from female's. Ventral surface of the basale with five spinose setae, terminal setae very long, subequal, smoothly curved with long hairs. Seventh limb in both sexes with two setae one long, one short. Caudal furca with seven pairs of claw setae that diminish in size dorsally, all with secondary spines along trailing edge, plus dorsally small unpaired seta with secondary spines. Between the first and second pairs of claw setae a verruciform process. Intromittent organ broad, widens distally with rounded tip.

Remarks

This genus is exceptional amongst halocyprid ostracods in that the females retain their eggs in a brood pouch within the carapace, releasing them as they complete the first juvenile instar. The earliest juvenile instar has two pairs of caudal furca spines and at each moult an extra pair is added. Most adult halocyprids have eight pairs of caudal furca spines, whereas *Euconchoecia* has seven pairs, which poses the question of whether the *Euconchoecia* moult just five times from hatching to maturation rather than the usual six of *Conchoecia* Dana, 1853. If *Euconchoecia* have evolved neotenously from the *Conchoecia* type of life cycle by a reduction in the number of moults from six to five, such an abbreviated life cycle would enable populations to respond quicker to any changes resulting from upwelling events.

2.6 *Euconchoecia chierchiae* Müller, 1890

(Figures 2.1 – 2.6, 2.21 A, B)

Synonymy

Euconchoecia chierchiae Müller, 1890: 277, Pl. XXVIII, fig.1–10. Brady, 1902:190, Pl. XXIV, fig.9–15. Vavra, 1906: 29, Pl.1, fig. 1–6. Skogsberg , 1920:740, fig.CXLVIII–CLI. Deevey, 1968: 116, fig. 62. Poulsen, 1969: 38, fig.12, 13. Tseng, 1969: 2, fig.1. George, 1977: fig.1, 2**.**

Paraconchoecia oblonga Cleve, 1900: 40.

Material

The material is not 'type' material, but material collected from Discovery station 8281 (see above)**.** Permanent preparations of dissected specimens used to prepare the illustrations in this paper have been deposited at the Natural History Museum, London: registration number BMNH 2009.316 for the female and BMNH 2009.317 for the male. Registration numbers BMNH 2009.318 – 327 are for the 32 females and 9 males retained in 80% ethanol.

Description A full redescription is merited because this is the type species for the genus. The meristic characters of the carapaces of both sexes, the frontal organs, first and second antennae, mouthparts and limbs are listed in Tables 2.2 to 2.9 together with comparative data for the other species examined: *E. aculeata* Scott 1894, and the two new species from the Gulf of Oman.

Female

Carapace (Figures 2.1 A, B) Mean length 1.24 ± 0.05 mm (n = 32). Carapace of exemplar specimen (Table 2.2) with length 1.28 mm, a height 0.56 mm and breadth 0.50 mm. Height:length ratio 43.8 %, breadth:length ratio 39.1 %. Carapace unsculptured. In lateral view slightly elongate: maximum height just posterior to mid-length. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a small spine. Spine slightly smaller on left valve. Dorsal margin arcs anteriorly up towards dorsal end of hinge between carapace valves. Both rostra curve ventrally, the left rostrum is the longer and more pointed. The 'asymmetrical' glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal organ (Table 2.2; Figure 2.1 C) Frontal organ fused into a single slender structure with rounded end that is just shorter than A1 and 18.9 %CL.

First antenna (Table 2.3; Figure 2.1 C) With five segments, but suture between fourth and fifth segments ill-defined. Limb length ~ 31 %CL. Fourth segment with ~ 24 thin walled bundle setae all 17 %CL. Fifth segment with four more unequal setae; a-seta quite short 5.1 %CL; b-seta 9.4 %CL; c-seta 17.2 %CL; d-seta 13.9 %CL.

Second antenna (Table 2.3; Figure 2.1 D) Protopodite 27.7 %CL. Length of first exopodite segment ~ half protopodite. Most swimming setae similar in length to protopodite, all but the shortest terminal seta have long hairs distally. Endopodite (Figure 2.1 E) with short, pointed, bare a- and b-seta. There are no c-, d- or e-setae. The f- and g-setae respectively 26.6 %CL and 44.9 %CL. The i-seta 13.3 %CL, but h- and j-setae are absent.

Mandible (Table 2.4; Figures 2.2 A, B) Coxale toothed edge of pars incisiva has two large and ten small smooth teeth. Distal tooth list slightly narrower with two large tusk-like teeth and ten small smooth teeth. The proximal tooth list very narrow, with two large and five small teeth. Outer margin of toothed edge of basal endite with a large dagger-shaped tooth, a slightly smaller, rounded, tubular tooth and six subserrate teeth. Two spinose setae are inserted laterally on basal endite. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with one short, bare, subterminal, dorsal seta and three finely spinose ventral setae. Second segment with one ventral and two dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla (Table 2.4; Figure 2.2 C) Basal segment with five anterior, one lateral and four posterior setae. Distal segment comparatively short and wide with six terminal claw setae, the posteriormost is longest, anterior claw with secondary spines.

Fifth limb (Table 2.5; Figure 2.2 D) Ventrally basale with five (2 + 1 + 2) setae all with secondary spines; laterally two plumose setae, dorsally a single long spinose seta - the remnant of the exopodite. First endopodite segment with two ventral setae and one dorsal seta, all spinose. Second segment with three unequal, curved terminal claw setae; middle claw the longest 5.7 %CL.

Sixth limb (Table 2.5; Figure 2.2 E) Basale with one proximal, two medial ventral spinose setae and a distal plumose seta, laterally a plumose seta and dorsally a terminal spinose seta. First endopodite segment with two ventral setae. Second segment with a single spinose seta both ventrally and dorsally. Third segment with three unequal spinose, terminal claw setae; longest middle claw 10.4 %CL.

Caudal furca (Table 2.5; Figure 2.2 F) Seven pairs of claw setae diminish in size dorsally; longest claw 15.2 %CL. All have secondary spines along their trailing edges.

Dorsal to the paired spines is a single seta with bilateral secondary spines. Between the first and second pairs of claw setae is a verruciform process.

Male

Carapace (Figures 2.3 A, B) Mean length 1.24 ± 0.06 mm (n = 9). Carapace of exemplar specimen (Table 2.6) with length of 1.26 mm, a height of 0.70 mm and breadth of 0.60 mm. Height:length ratio 55.6 %, breadth:length ratio 47.6 %. Carapace unsculptured. Maximum height just anterior to mid-length. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a small spine. On the left valve the spine is slightly smaller. Dorsal margin arcs anteriorly up towards dorsal end of hinge between carapace valves. Both rostra forward pointing and of the same length. The 'asymmetrical' glands open at a similar height on the posterior margin of each valve just below the spine at the posterior dorsal corner.

Frontal organ (Table 2.6; Figure 2.3 C) Frontal organ is fused into a slender structure with a rounded end, shorter than A1 and 23.2 %CL.

First antenna (Table 2.7; Figure 2.3 C) With five well-defined segments. Limb length ~ 31 %CL. As in the female, fourth segment with ~ 24 thin walled bundle setae all 17.5 %CL. Fifth segment with five more unequal setae: a-seta 8.3 %CL; b-seta 18.1 %CL; c-seta 38.9 %CL; d-seta 42.5 %CL; e-seta 65.1 %CL.

Second antenna (Table 2.7; Figure 2.3 D) Protopodite 38.5 %CL. Length of first segment of exopodite ~ half protopodite. Most swimming setae similar in length to protopodite, all but the shortest have long hairs distally. Endopodite with short, pointed a- and b-setae. There are no c-, d- or e-setae. The f- and g-setae respectively 22.4 %CL and 79.8 %CL. Right endopodite (Figure 2.4 B) with elongated clasping organ in form of hook with long proximal shank and very long curved end piece 9.1 %CL. The h-, i- and j-setae attached distally to basal shank, h-seta is short 3.4 %CL and curves over bases of other two, i-seta longest 15.9 %CL. Left endopodite (Figure 2.4 A) ‘hook’ reduced to just basal shank with three setae.

Mandible, Maxilla, Fifth limb (Tables 2.8, 2.9; Figures 2.4 C – E, 2.5 A) Structure and arrangement of setae for mandible, maxilla and fifth limb are same as for female.

Sixth limb (Table 2.9; Figure 2.5 B) Basale with five spinose setae ventrally, one lateral spinose seta and one bare dorsal exopodal seta. First endopodite segment with two ventral setae. Second endopodite segment with a single seta both ventrally and dorsally. Third segment with three subequal terminal setae, very long, evenly curved ventrally with long hairs 28.6 %CL.

Caudal furca (Table 2.9; Figure 2.5 C) Structure and arrangement of furcal claws similar to female. The longest claw is 18.7 %CL.

Intromittent organ (Table 2.9; Figure 2.5 C) Male copulatory appendage is exceptionally long, 27.4 %CL.

Remarks

The original description of *E. chierchiae* by Müller (1890) and subsequent redescription (Müller 1906**)** specified a wide size range; females from 1.15 to 1.53 mm and males from 1.15 to 1.45 mm. Size is a significant taxonomic feature of halocyprid ostracods, so a wide range such as this often suggests there may be more than one species present. The redescriptions of *E. chierchiae* by Brady (1902) and by Vavra (1906) were considered doubtful by Skogsberg (1920), and the illustration by Skogsberg (1920) of a female specimen in lateral aspect differs from those of Müller (1890, 1906). *Euconchoecia chierchiae* as described by George (1977) from the Indian Ocean appears very similar to Atlantic *E. chierchiae* as described by Müller (1890). Deevey (1968) and later Angel (1999) identified and illustrated *E. chierchiae* from off Bermuda, and recently specimens from waters west of Bermuda have had the CO1 gene sequenced (Angel, pers. com). However, critical comparisons of these two authors' descriptions and figures deviate from those of both Müller (1906) and Skogsberg (1920), and the attributions of their specimens to this species remain open to question (Figure 2.6). There is a now a need for systematic and molecular studies to clarify the status of this species. Unfortunately, despite the remarkably high abundances of *Euconchoecia* in tropical waters especially in the Pacific, no sequencing of this genus has been undertaken, and the Gulf of Oman material is unsuitable for molecular sequencing because it was initially preserved in formalin.

2.7 *Euconchoecia aculeata* (Scott, 1894)

(Figures 2.7 – 2.10, 2.21 C, D)

Synonymy

Halocypris aculeata Scott, 1894: S 142, Pl.XV, figs.5, 6, 33, 38.

Euconchoecia aculeata Cleve, 1905:131. Müller, 1906:129, Pl.XXXII, figs.18–20, 22–26. Müller, 1912: 95. Poulsen, 1969: 41, fig.15. Tseng, 1969:18, fig 4.George, 1977: figs.1–5.

Type material Permanent preparations of the dissected specimens selected as lectotype and paralectotype and used in this detailed description of the species are deposited at the Natural History Museum, London registration number BMNH 2009.328 for the lectotype (female) and BMNH 2009.329 for the paralectotype (male). The remaining undissected paralectotypes retain the original registration number, 1893.4.22.14-17.

Description The meristic characters of the carapaces of males and females, and the frontal organs, first and second antennae, mouthparts and limbs are listed in Tables 2 to 9 together with comparative data for the other species described here.

Female

Carapace (Figures 2.7 A, B) Material deposited in the Natural History Museum contained two females: one measured 1.18 mm. The other, selected as lectotype (Table 2.2), has length of 1.28 mm, a height of 0.64 mm and breadth 0.42 mm. Height:length ratio 50.0 %, breadth:length ratio of 32.8 %. Carapace unsculptured. Lateral view elongate. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a small spine. On the left valve the spine is the smaller. Dorsal margin straight and parallel to the ventral margin. Both rostra curve ventrally, with the left rostral process longer and more pointed. The ‘asymmetrical’ glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal Organ (Table 2.2; Figure 2.7 C) Frontal organ fused into a slender structure with a rounded end that is slightly longer than A1 and 22.3 %CL.

First antenna (Table 2.3; Figure 2.7 C) With five segments, but suture between fourth and fifth segments ill-defined. Limb length is ~ 34 %CL. Fourth segment with ~ 24 thin walled bundle setae all 17.0 %CL. Fifth segment with four more unequal setae, the a-seta short 3.1 %CL; b-seta 6.1 %CL; c-seta 14.5 %CL; d-seta 11.5 %CL.

Second antenna (Table 2.3; Figure 2.7 D) Protopodite 29.3 %CL. Length of first exopodite segment ~ half protopodite. Most swimming setae are similar length to protopodite, all but the shortest terminal seta have long hairs distally. Endopodite (Figure 2.7 E) with short, pointed, bare a- and b-seta. There are no c-, d- or e-setae. The f- and g-setae respectively 25.4 %CL and 35.2 %CL. The i-seta 23.0 %CL, but the h- and j-setae are absent.

Mandible (Table 2.4; Figure 2.8 A) Coxale toothed edge of pars incisiva has two large and ten small smooth teeth. Distal tooth list slightly narrower with two large tusk-like teeth and ten small smooth teeth. Proximal tooth list very narrow, with two large and five small teeth. Outer margin of toothed edge of basal endite with a large dagger-shaped tooth, a slightly smaller, rounded, tubular tooth and six subserrate triangular teeth. Two spinose setae are inserted laterally on the basal endite. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with one short, bare, subterminal, dorsal seta and three finely spinose ventral setae. Second segment with one ventral and two dorsal setae all finely spinose. Third segment with seven spinose terminal setae, one very long and robust.

Maxilla (Table 2.4; Figure 2.8 B) Basal segment with five anterior, one lateral and four posterior setae. Distal segment comparatively short and wide with six terminal claw setae, the posteriormost is longest, anterior claw with secondary spines.

Fifth limb (Table 2.5; Figure 2.8 C) Ventrally basale with five (2 + 1 + 2) setae all with secondary spines, laterally two plumose setae, dorsally a single long dorsal spinose seta - the remnant of the exopodite. First endopodite segment with two ventral setae and one dorsal seta, all spinose. Second segment with three unequal curved terminal claw setae of unequal length; middle claw the longest 6.0 %CL.

Sixth limb (Table 2.5; Figure 2.8 D) Basale with one proximal, two medial ventral spinose setae and a distal plumose seta, laterally a plumose seta and dorsally a terminal spinose seta. First endopodite segment with two ventral setae. Second segment with a single spinose seta both ventrally and dorsally. Third segment with three unequal, spinose terminal claw setae; longest middle claw 8.1 %CL.

Caudal furca (Table 2.5; Figure 2.8 E) Seven pairs of claw setae diminish in size dorsally; longest claw 14.1 %CL. All have secondary spines along their trailing edges. Dorsal to the paired spines is a single seta with bilateral secondary spines. Between the first and second pair of claw setae is a verruciform process.

Male

Carapace (Figures 2.9 A, B) Material deposited in the Natural History Museum contained two males. One measured 1.14 mm. The paralectotype (Table 2.6) with a length of 1.06 mm, height of 0.60 mm and breadth of 0.46 mm. Height:length ratio 56.6 %, breadth:length ratio 43.4 %. Carapace unsculptured. In lateral view maximum carapace height is just anterior to mid-length. Ventral margin curves uniformly. Dorsal margin curves upwards towards the rostral processes. Posterior dorsal corner of both valves furnished with a small spine. On the left valve the spine is slightly the smaller. Both rostra curve ventrally, the left rostrum is slightly smaller. The specimen was damaged, so measurements imprecise. The 'asymmetrical' glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal organ (Table 2.6; Figure 2.9 C) Frontal organ fused into a single slender structure with rounded end that is shorter than A1 and 22.2 %CL.

First antenna (Table 2.7; Figure 2.9 C) With five well-defined segments. Fourth segment with ~ 24 thin walled bundle setae. All broken, so no measurements obtained. Fifth segment with five unequal setae. All broken, so no measurements obtained.

Second antenna (Table 2.7; Figure 2.9 D) Protopodite 38.2 %CL. Length of first exopodite segment ~ half prodopodite. Swimming setae shorter than the protopodite and all but the shortest have long hairs distally. Endopodite with short, pointed, bare a- and b- seta. There are no c-, d- or e-setae. The f-seta and g-seta respectively 36.8 %CL and 38.4 %CL. Right endopodite (Figure 2.9F) with an elongated clasping organ in the form of a hook with long proximal shank and curved end piece 1.7 %CL. The h-seta is short 1.9 %CL with long i-seta 16.0 %CL. Left endopodite (Figure 2.9 E) 'hook' is reduced to basal shank with three setae terminally.

Mandible, Maxilla (Table 2.8; Figures 2.10 A, B) The full detailed structure of these limbs can not be described because of the poor state of preservation of the material. Structure and arrangement of setae on the endopodite and the structure of the maxilla are same as female.

Fifth limb Missing.

Sixth limb (Table 2.9; Figure 2.10 C) Basale with five spinose setae ventrally, one lateral spinose seta and one bare dorsal seta. First endopodite segment with two ventral setae. Second endopodite segment with a single seta both ventrally and dorsally. Terminal setae broken.

Caudal furca (Table 2.9; Figure 2.10 D) Structure and arrangement of the furcal claws is same female. Longest claw is 17.5 %CL.

Intromittent organ (Table 2.9; Figure 2.10 E) The male copulatory appendage is exceptionally long, 27.4 %CL.

Remarks

A full and detailed description of the type material is given here because the original description is so incomplete that it has undoubtedly led to confusion in the subsequent literature. By unambiguously describing all its characters, even when very similar, if not identical, to those described above for E. *chierchiae*, confusion should be avoided in future.

Scott's original description of this species as *Halocypris aculeata* (Scott 1894) was vague and incomplete. Cleve (1905), with approval from Scott, transferred this species to the genus *Euconchoeci*a, since Scott's specimens were clearly not *Halocypris,* and Müller had described his new genus *Euconchoecia.* The description of *E. aculeata* by Müller (1912) records a length of 0.9 – 1.05 mm for females and 0.95 mm for males.

This is smaller than the type specimens deposited by Scott at the Natural History Museum, London. Poulsen (1969) and Tseng (1969) both reported *E. aculeata* from various locations outside the Atlantic without re-examining Scott's material. Given the inadequate quality of the original description, subsequent records of *E. aculeata* remote from the type locality require confirmation.

The species *E. aculeata* is very similar to *E. chierchiae* and both are of similar size. The female of *E. aculeata* is more elongate and the rostrum is narrower and more downward pointing in both sexes (Figure 2.21). The frontal organ of female *E. aculeata* is marginally longer than the first antenna (Table 2.2), and in the male the second antenna right clasper shank length is very much smaller than that of *E. chierchiae* (Table 2.7). These characters readily distinguish these two species.

2.8 *Euconchoecia omanensis* sp.nov.

(Figures 2.11 – 2.15, 2.21 E, F)

Type material Permanent preparations of the dissected holotype and allotype used in this description are deposited at the Natural History Museum, London registration number BMNH 2009.330 for the holotype (female) and BMNH 2009.331 for the allotype (male). Registration numbers BMNH 2009.332 – 341 are for the remaining female and male paratypes retained in 80% ethanol.

Etymology The specific name refers to the type locality of the Gulf of Oman.

Description The meristic characters of the carapaces of males and females, and the frontal organs, first and second antennae, mouthparts and limbs are listed in Tables 2.2 to 2.9 together with comparative data for the other species described here.

Female

Carapace (Figures 2.11 A, B) Mean length measured 1.42 ± 0.06 mm (n = 100). Carapace of holotype (Table 2.2) with length of 1.42 mm, a height of 0.46 mm and breadth of 0.40 mm. Height:length ratio 32.4 %, breadth:length ratio 28.2 %. Carapace is unsculptured. In lateral view elongate: maximum height is just anterior to mid-length. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a spine. On the left valve the spine is much smaller. Dorsal margin arcs anteriorly up towards dorsal end of hinge between carapace valves. Both rostra narrow and point forward, the left rostral process longer and more pointed. The 'asymmetrical' glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal organ (Table 2.2; Figure 2.11 C) Frontal organ fused into a slender structure with rounded end, that is significantly longer than A1 and 18.7 %CL.

First antenna (Table 2.3; Figure 2.11 C) With five segments, but the suture between fourth and fifth segments ill-defined. Limb length is ~ 35 %CL. Fourth segment with ~ 24 thin walled bundle setae all 9.2 %CL. Fifth segment with four more unequal setae, a-seta quite short 2.1 %CL; b-seta 3.5 %; c-seta 10.0 %CL; d-seta 7.7 %CL.

Second antenna (Table 2.3; Figure 2.11 D) Protopodite is 24.6 %CL. Length of first exopodite segment is ~ half protopodite. Most swimming setae are similar in length to protopodite, all but the shortest terminal seta have long hairs distally. Endopodite (Figure 2.11 E) with short, pointed, bare a- and b-setae. There are no c-, d- or e-setae. The f- and g-setae respectively 17.8 %CL and 23.2 %CL. The i-seta is 7.2 %CL, but h- and j-setae are absent.

Mandible (Table 2.4; Figures 2.12 A, B) Coxale toothed edge of pars incisiva has two large and ten small smooth teeth. Distal tooth list slightly narrower with two large tusk-like teeth and ten small smooth teeth. Proximal tooth list very narrow, with two large and five small teeth. Outer margin of toothed edge of basal endite with a large dagger-shaped tooth, a slightly smaller, rounded, tubular tooth and six subserrate teeth. Two spinose setae are inserted laterally on basal endite. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with one short, bare, subterminal dorsal seta and three finely spinose ventral setae. Second segment with one ventral and two dorsal setae all finely spinose. Third segment with seven spinose terminal setae, one very long and robust.

Maxilla (Table 2.4; Figure 2.12 C) Basal segment with five anterior, one lateral and four posterior setae. Distal segment comparatively short and wide, with six terminal claw setae, the posteriormost is longest, anterior claw with secondary spines.

Fifth limb (Table 2.5; Figure 2.12 D) Ventrally basale with five (2 + 1 + 2) setae all with secondary spines, laterally two plumose setae, dorsally a single long spinose seta. First endopodite segment with two ventral setae and one dorsal seta, all spinose. Second segment with three unequal curved terminal claw setae; middle claw the longest and is 4.1 %CL.

Sixth limb (Table 2.5; Figure 2.12 E) Basale with one proximal, two medial ventral spinose setae and a distal plumose seta, laterally a plumose seta and dorsally a terminal spinose exopodal seta. The first endopodite segment with two ventral setae. Second segment with a single spinose seta both ventrally and dorsally. Third segment with three unequal spinose terminal claw setae; longest middle claw is 7.1 %CL.

Caudal furca (Table 2.5; Figure 2.12 F) Seven pairs of claw setae diminish in size dorsally; longest claw 10.4 %CL. All have secondary spines along their trailing edge. Dorsal to the paired spines is a single seta with bilateral secondary spines. Between first and second pair of claw setae is a verruciform process.

Male

Carapace (Figures 2.13 A, B) Mean length measured 1.15 ± 0.04 mm (n = 100). Carapace of allotype (Table 2.6) with length of 1.20 mm, a height of 0.44 mm and breadth of 0.40 mm. Height:length ratio 36.7 %, breadth:length ratio 33.3 %. Carapace unsculptured. Maximum carapace height just anterior to mid-length. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a small spine. On the left valve the spine is smaller. The dorsal margin arcs anteriorly up towards dorsal end of hinge between carapace valves. Both rostra broad, curve ventrally, the left rostral process is longer. The 'asymmetrical' glands open at a similar height on the posterior margin of each valve just below the spine at posterior dorsal corner.

Frontal organ (Table 2.6; Figure 2.13 C) Frontal organ fused into a single slender structure with a rounded end, that is significantly longer than A1 and 31.3 %CL.

First antenna (Table 2.7; Figure 2.13 C) With five well-defined segments. Limb length ~ 35 %CL. Fourth segment with ~ 24 thin walled bundle setae all 14.4 %CL. Fifth segment with five more unequal setae: a-seta 8.8 %CL; b-seta 15.0 %CL; c-seta 18.3 %CL; d-seta 32.1 %CL; e-seta 46.3 %CL.

Second antenna (Table 2.7; Figure 2.13 D) Protopodite 37.1 %CL. Length of first exopodite segment ~ third of protopodite. Most swimming setae similar in length to protopodite, all but the shortest have long hairs distally. Endopodite with short, pointed, bare a- and b-seta. There are no c-, d- or e-setae. The f-seta very long g-seta respectively 39.2 %CL and 60.0 %CL. Right endopodite (Figure 2.14 A) with elongated clasping organ in form of hook with a long proximal shank and very long curved end piece 5.4 %CL. The h-seta is short and curved 2.9 %CL; i-seta 19.2 %CL;

j-seta 9.6 %CL. Left endopodite (Figure 2.14 B) the hook reduced to just basal shank with three setae terminally.

Mandible, Maxilla, Fifth limb (Tables 2.8, 2.9; Figures 2.14 C - E, 2.15 A) Structure and arrangement of setae of mandible, maxilla and fifth limb are same as female.

Sixth limb (Table 2.9; Figure 2.15 B) Basale with five spinose setae, one lateral spinose seta and one bare dorsal exopodal seta. First segment with two ventral setae. Second segment with a single bare seta both ventrally and dorsally. Third segment with three very long subequal terminal setae, with long hairs distally 30.4 %CL.

Caudal furca (Table 2.9; Figure 2.15 C) Structure and arrangement of claws same as female. Longest claw 12.5 %CL.

Intromittent organ (Table 2.9; Figure 2.15 C) Male copulatory appendage long 19.6 %CL.

Remarks

Euconchoecia omanensis should be regarded as a separate species on the basis of the following combination of characters: both females and males are more elongate than *E. chierchiae* and *E. aculeata*; the height:length ratio of *E. omanensis* was 32.4% and the breadth:length ratio was 28.2 %; the spines on the posterior dorsal corner of the female were almost twice the length of the spines of *E. chierchiae*, and in the male the left spine on the posterior dorsal corner was 2 % longer, whilst the right spine was 3% longer. In both sexes the frontal organ reached well beyond the first antenna and on the second antenna the right clasper shank length was significantly smaller than in *E. chierchiae*, but longer than in *E aculeata*.

2.9 *Euconchoecia hormuzensis* sp. nov.

(Figures 2.16 – 2.20, 2.21G, H)

Type material Permanent preparations of the dissected holotype and allotype used in this description are deposited at the Natural History Museum, London, registration number BMNH 2009.342 for the holotype (female) and BMNH 2009.343 for the allotype (male). Registration numbers BMNH 2009.344 – 353 are for the 48 female and 36 male paratypes retained in 80% ethanol

Etymology The specific name refers to the type locality close to the Gulf of Hormuz.

Description The meristic characters of the carapaces of males and females, and the frontal organs, first and second antennae, mouthparts and limbs are listed in Tables 2.2 to 2.9 together with comparative data for the other species described here.

Female

Carapace (Figures 2.16 A, B) Mean length measured 1.04 ± 0.05 mm (n = 48). Carapace of holotype (Table 2.2) with length of 1.00 mm, height of 0.42 mm and breadth of 0.40 mm. Height:length ratio 42.0 %, breadth:length ratio of 40.0 %. Carapace unsculptured. In lateral view slightly elongate: maximum height just anterior to mid-length. Ventral margin curves smoothly. Posterior dorsal corner of both valves furnished with a small spine. On the left valve the spine is slightly smaller. Dorsal margin arcs anteriorly up towards dorsal end of hinge between carapace valves. Both rostra curve ventrally and are of the same length. The ‘asymmetrical’ glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal Organ (Table 2.2; Figure 2.16 C) Frontal organ fused into a single slender structure with a rounded end that is slightly longer than A1 and 20.3 %CL.

First antenna (Table 2.3; Figure 2.16 C) With five segments, but suture between fourth and fifth segment ill-defined. Limb length is ~ 37 %CL. Fourth segment with ~ 24 thin walled bundle setae all 16.3 %CL. Fifth segment with four more setae of different lengths; a-seta quite short 3.8 %CL; b-seta 5.5 %CL; c-seta 17.0 %CL; d-seta 13.5 %CL.

Second antenna (Table 2.3; Figure 2.16 D) Protopodite 30%CL. Length of first exopodite segment ~ half length of protopodite. Swimming setae shorter in length than protopodite, all but shortest have long hairs distally. Endopodite (Figure 2.16 E) with short, pointed, bare a- and b-seta. There are no c-, d- or e-setae. The f- and g-setae respectively 24.0 %CL and 43.5 %CL. The i-seta is long 11.5 %CL, but h- and j-setae are absent.

Mandible (Table 2.4; Figures 2.17 A, B) Coxale toothed edge of pars incisiva has two large and ten small smooth teeth. Distal tooth list narrower with two large tusk-like teeth and ten small smooth teeth. Proximal tooth list very narrow, with two large and five small teeth. Outer margin of toothed edge of basal endite with a large dagger-shaped tooth, a slightly smaller, rounded, tubular tooth and six subserrate triangular teeth. Two spinose setae are inserted laterally on basal endite. Exopodite represented by moderately long plumose seta of moderate length inserted on outer margin of basis. First endopodite segment with one short, bare, subterminal, dorsal seta and three finely spinose ventral setae. Second segment with one ventral and two dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla (Table 2.4; Figure 2.17 C) Basal segment with five anterior, one lateral and four posterior setae. Distal segment comparatively short and wide with six terminal claw setae; the posteriormost is longest; anterior claw with secondary spines.

Fifth limb (Table 2.5; Figure 2.17 D) Ventrally basale with five (2 + 1 + 2) setae all with secondary spines; laterally plumose setae, dorsally a single long spinose seta – the remnant of the exopodite. First endopodite segment with two ventral setae and one dorsal seta, all spinose. Second segment with three unequal spinose, terminal claw setae; longest middle claw 5.5 %CL.

Sixth limb (Table 2.5; Figure 2.17 E) Basale with one proximal, two medial ventral spinose setae and a distal plumose seta, laterally a plumose seta and dorsally a terminal spinose exopodal seta. First endopodite segment with two ventral setae. Second segment with a single spinose seta both ventrally and dorsally. Third segment with three unequal spinose, terminal claw setae; longest middle claw 8.5 %CL.

Caudal furca (Table 2.5; Figure 2.17 F) Seven pairs of claw seta diminish in size dorsally; longest claw 12.0 %CL. All have secondary spines along the trailing edges. Dorsal to the paired spines is a small unpaired seta with bilateral secondary spines. Between the first and second pair of claw setae is a verruciform process.

Male

Carapace (Figures 2.18 A, B) Mean length measured 1.00 ± 0.03 mm (n = 36). Allotype (Table 2.6) with length of 0.98 mm, a height of 0.40 mm and breadth of 0.40 mm. Height:length ratio 40.8 %, breadth:length ratio 40.8 %. Carapace unsculptured. In lateral view maximum height just anterior to mid-length. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a small spine. On the left valve the spine is slightly smaller. Dorsal margin arcs anteriorly up towards carapace hinge between carapace valves. Both rostra curve ventral, the left is the longer and more pointed. The ‘asymmetrical’ glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal organ (Table 2.6; Figure 2.18 C) Frontal organ fused into a single slender structure with a rounded end that is slightly longer than A1 and 21.1 %CL.

First antenna (Table 2.7; Figure 2.18 C) With five well-defined segments. Limb length ~ 34%CL. Fourth segment with ~ 24 thin walled bundle setae all 17.1 %CL. Fifth segment with five more seta; a-seta 3.7 %CL; b-seta 4.6 %CL; c-seta 13.8 %CL; d-seta 34.2 %CL; e-seta 50.0 %CL.

Second antenna (Table 2.7; Figure 2.18 D) Protopodite 40.8 %CL. Length of first exopodite segment 15.3 %CL approximately third protopodite. Most swimming setae are about two thirds length of protopodite, all but shortest have long hairs distally. Endopodite with short, pointed, bare a- and b-setae. There a no c-, d- or e-setae. The f-seta and g-seta respectively 39.8 %CL and 119.9 %CL. Right endopodite (Figure 2.19 B) with elongated clasping organ in form of hook with a long proximal shank and long curved end piece 6.4 %CL. The h-seta is short and curved 2.8 %CL; i-seta 20.7 %CL; j-seta 9.7 %CL. Left endopodite (Figure 2.19A) ‘hook’ reduced to just basal shank with three setae terminally.

Mandible, Maxilla, Fifth limb (Tables 2.8, 2.9; Figures 2.19 C - E, 2.20 A) Mandible, maxilla and fifth limb structure and arrangement of setae are same as female.

Sixth limb (Table 2.9; Figure 2.20 B) Basale with five spinose setae, one lateral spinose seta and one bare dorsal exopodal seta. First segment with two ventral setae. Second segment with a single bare seta both ventrally and dorsally. Third segment with three subequal terminal setae, all very long, evenly curved with long hairs distally 34.7%CL.

Caudal furca (Table 2.9; Figure 2.20 C) Structure and arrangement of the furcal claws are same as female; longest claw 14.5 %CL.

Intromittent organ (Table 2.9; Figure 2.20 C) The male copulatory appendage is long 20.9 %CL.

Remarks

Euconchoecia hormuzensis is to be regarded as a separate species on the basis of both sexes being markedly smaller in length, breadth and height than the other three species, and the height:length ratio in both sexes is approximately 40%, whilst the breadth:length ratio in both sexes is approximately 40%. The spines on the posterior dorsal corner are similar in length and the rostral processes are quite short. The frontal organ is marginally longer than the first antenna in both sexes, whereas in *E. chierchiae* the frontal organ is shorter and in *E. aculeata* it is marginally longer in the female, but shorter in the male. In *E. omanensis* the frontal organ is considerably longer than the first antenna in both sexes. On the second antenna the right shank length, at 6.4 %, is greater than the shank length of *E. aculeata* and *E. omanensis*, but less than the shank length of *E. chierchiae*. These differences are sufficient to justify the establishment of a new species.

2.10 Discussion

Detailed examination of four *Euconchoecia* species reveals substantial differences between them. The length of the carapace, and the height:length ratio of the carapace varies considerably between all four species (Tables 2.2, 2.6; Figure 2.21). Although each species bears spines on the posterior dorsal corner, the length of spine on each valve is species specific (Tables 2.2, 2.6). The rostrum size and shape are important species-level differences (Figure 2.21). There are also clear differences between the four species in the length of the frontal organs relative to the length of the first antenna in both sexes (Tables 2.2, 2.6). The male and female frontal organs of *E. omanensis* are particularly long, whilst those of *E. chierchiae* are shorter than the antenna in both sexes.

There are clear differences in size of the protopodite of the second antenna between the sexes, although not between species (Tables 2.3, 2.7). In the males there is a marked disparity between the left and right endopodites. The right endopodite bears an elongated clasping organ in the form of a hook with a long proximal shank. The shank length, however, varies considerably between species (Table 2.7). There were no other interspecific differences.

There is some uncertainty in the literature regarding the number of spines on the caudal furca in some *Euconchoecia* species. Tseng (1969) in describing *Euconchoecia elongata* illustrated seven pairs of spines, but when describing the developmental stages of this species Tseng (1975) recorded 8 pairs of spines on the caudal furca. Poulsen (1969) for the generic diagnosis of *Euconchoecia* stated that the number of spines on the caudal furca is the same as for *Bathyconchoecia* Deevey (1968) namely eight pairs, but in describing *Euconchoecia chierchiae* and *Euconchoecia aculeata* he refers to Skogsberg (1920) who described seven pairs with a verruciform process between the first and second spine. All four species examined in this paper have seven pairs of spines with a verruciform process between the first and second spines.

All species of *Euconchoecia* have been collected from near surface coastal waters with an oceanic influence. *Euconchoecia chierchiae* has been identified in the Pacific, Atlantic and Indian Oceans, and has been regarded as a ubiquitous species, although no exact data on abundances are available as few recorded in oceanic waters. Poulsen (1969) records small numbers of *Euconchoecia* in the Atlantic and only in tropical and sub-tropical waters. Baker (1977) recorded four specimens from Cedar Bayou off Texas, but from his illustrations his exact identification is uncertain. Angel (1979) reported *E. chierchiae* absent from the NE Atlantic at 30ºN 23ºW, and a density of 0.6m^3 in the night sample at 0 – 10 m at 32ºN 65ºW. The true geographical range remains to be determined given the confusion apparent in the earlier identifications of this species. There has also been much confusion over the identification of *E. aculeata*, so its geographical range is also difficult to determine. *E. omanensis* and *E. hormuzensis* were both found in large numbers in the Gulf of Oman, and may have become specifically adapted to the changing food sources caused by the upwelling events of the seasonal monsoons.

2.11 Key to the species of *Euconchoecia* in this chapter

Female

1 Posterior dorsal corner, left tip to posterior hinge ca. 6%CL 2

Posterior dorsal corner, left tip to posterior hinge ca. 12%CL 3

2 CL ca. 1.3 mm; carapace height ca. 44%CL; frontal organ marginally shorter than first antenna .... *chierchiae*

CL ca. 1.3 mm; carapace height ca. 50%CL; frontal organ marginally longer than first antenna .... *aculeata*

3 CL ca. 1.0 mm; carapace height ca. 42%CL; frontal organ marginally longer than first antenna .... *hormuzensis*

CL ca. 1.4 mm; carapace height ca. 33%CL; frontal organ significantly longer than first antenna .... *omanensis*

Male

1 Carapace height ca. 55%CL; frontal organ shorter than first antenna 2

Carapace height ca. 40%CL; frontal organ longer than first antenna 3

2 CL ca. 1.3 mm; right clasper shank length ca. 9%CL .... *chierchiae*

CL ca. 1.0 mm; right clasper shank length ca 2%CL .... *aculeata*

3 CL ca. 1.0 mm; frontal organ marginally longer than first antenna ... *hormuzensis*

CL ca. 1.2 mm; frontal organ significantly longer than first antenna .... *omanensis*

2.12 Tables and Figures

Table 2.1. Density of *Euconchoecia* from the Gulf of Oman samples.

Station 54001	Depth (metres)	Day/ Night	Ostracod Nos.		*Euconchoecia*		
			Totals	Per 1000 cubic metres	Totals	Per 1000 cubic metres	Percentage
#21	0 - 50	Night	14456	5616	6412	2491	44.40%
#27	0 - 50	Day	2796	2186	2238	1750	80.00%
#20	50 - 100	Night	23336	10115	6540	2835	28.00%
#26	50 - 100	Day	9884	8433	6288	5365	63.60%
#25	100 - 150	Day	19816	15530	152	119	0.80%
#19	100 - 157	Night	19688	7646	41	16	0.20%
#03	150 - 200	Day	12684	4899	34	13	0.30%
#06	152 - 201	Night	6834	2489	8	3	0.10%

Table 2.2. Female *Euconchoecia* species differences
(n = 1 for each species, %CL = Carapace Length, PDC = posterior dorsal corner).

	chierchiae	*aculeata*	*omanensis*	*hormuzensis*
Carapace				
length	1.28 mm	1.28 mm	1.42 mm	1.00 mm
height	0.56 mm	0.64 mm	0.46 mm	0.42 mm
breadth	0.50 mm	0.42 mm	0.40 mm	0.40 mm
height/length %	43.8%	50.0%	32.4%	42.0%
breadth/length %	39.1%	32.8%	28.2%	40.0%
PDC, left tip to posterior hinge (% CL)	6.3%	6.6%	13.0%	11.0%
PDC, right tip to posterior hinge (% CL)	7.0%	9.8%	15.8%	11.5%
rostrum, left tip to anterior hinge (% CL)	14.5%	15.6%	15.1%	12.0%
rostrum, right tip to anterior hinge (% CL)	13.3%	12.1%	11.6%	12.0%
incisure, left rostrum tip to inner edge (% CL)	12.5%	14.5%	14.1%	10.0%
incisure, right rostrum tip to inner edge (% CL)	9.4%	10.5%	11.3%	9.5%
Frontal organ				
stem and capitulum length (% CL)	18.9%	22.3%	18.7%	20.3%
length relative to antenna 1	Slightly shorter	marginally longer	significantly longer	slightly longer

Table 2.3. Female *Euconchoecia* species differences
(n = 1 for each species, %CL = Carapace Length).

	chierchiae	*aculeata*	*omanensis*	*hormuzensis*
Antenna 1				
length segment 2 (% CL)	7.4%	8.2%	6.5%	7.0%
length segment 3 (% CL)	4.3%	7.2%	4.4%	3.0%
length segment 4 (% CL)	1.6%	4.5%	3.3%	2.4%
approximate total length	31.0%	34.0%	35.0%	37.0%
bundle setae number	approximately 24	approximately 24	approximately 24	approximately 24
bundle setae length (% CL)	17.0%	17.0%	9.2%	16.3%
a-seta (% CL)	5.1%	3.1%	2.1%	3.8%
b-seta (% CL)	9.4%	6.1%	3.5%	5.5%
c-seta (% CL)	17.2%	14.5%	10.0%	17.0%
d-seta (% CL)	13.9%	11.5%	7.7%	13.5%
Antenna 2				
protopodite (% CL)	27.7%	29.3%	24.6%	30.0%
exopodite 1 (% CL)	14.8%	13.7%	10.2%	13.0%
exopodite 2 - 9 (% exopodite 1)	53.9%	45.7%	37.9%	53.8%
longest swimming seta (% CL)	27.0%	30.9%	24.1%	24.5%
shortest swimming seta (% CL)	3.8%	3.1%	2.1%	2.0%
endopodite segment 1 (% CL)	9.2%	9.4%	7.2%	9.3%
a-seta	1.8%	1.2%	1.6%	2.3%
b-seta	3.1%	3.5%	3.2%	3.5%
endopodite segment 2 (% CL)	4.1%	2.3%	2.3%	2.0%
f-seta (% CL)	26.6%	25.4%	17.8%	24.0%
g-seta (% CL)	44.9%	35.2%	23.2%	43.5%
i-seta (% CL)	13.3%	23.0%	7.2%	11.5%

Table 2.4. Female *Euconchoecia* species similarities
(n = 1 for each species, %CL = Carapace Length).

	chierchiae	*aculeata*	*omanensis*	*hormuzensis*
Mandible				
basale	1 plumose	1 plumose	1 plumose	1 plumose
endopodite segment 1 dorsal setae	1	1	1	1
endopodite segment 1 ventral setae	3	3	3	2
endopodite segment 2 dorsal setae	2	2	2	2
endopodite segment 2 ventral setae	1	1	1	1
endopodite segment 3 terminal setae	7	7	7	7
endopodite segment 3 longest claw (% CL)	15.8%	16.0%	12.9%	16.0%
endopodite segment 3 longest claw (% limb)	93.2%	93.2%	83.9%	94.1%
teeth on basal endite	2 + 6	2 + 6	2 + 6	2 + 6
pars incisiva	2 + 10	2 + 10	2 + 10	2 + 10
distal tooth list	2 + 10	2 + 10	2 + 10	2 + 10
proximal list	2 + 5	2 + 5	2 + 5	2 + 5
setae laterally on endite	2 +2	2 + 2	2 + 2	2 + 2
exopodite	1 plumose	1 plumose	1 plumose	1 plumose
Maxilla				
basal segment anterior setae	5	5	5	5
basal segment lateral setae	1	1	1	1
basal segment posterior setae	4	4	4	4
terminal spines	fine hairs	fine hairs	fine hairs	fine hairs
distal segment claw setae	3	3	3	3
distal segment normal setae	3	3	3	3

Table 2.5. Female *Euconchoecia* species similarities
(n = 1 for each species, %CL = Carapace Length).

	chierchiae	*aculeata*	*omanensis*	*hormuzensis*
Fifth limb				
basale ventral setae	2 + 2 + 1	2 + 2 + 1	2 + 2 + 1	2 + 2 + 1
basale lateral setae	2	2	2	2 plumose
basale dorsal setae	1 long	1 long	1 long	1 long
endopodite segment 1 ventral setae	2	2	2	2
endopodite segment 1 dorsal setae	1	1	1	1
height/lenth %	45.2%	56.3%	76.0%	57.7%
longest terminal seta % CL	5.7%	6.0%	4.1%	*5.5%*
longest seta/length segment 2	341.2%	554.5%	522.2%	525.0%
longest seta/ length limb	55.8%	58.7%	58.0%	60.9%
Sixth limb				
basale ventral setae	3 + 1 plumose	3 + 1	3 + 1 plumose	3 + 1
basale lateral setae	1 plumose	1 plumose	1 plumose	1 plumose
basale dorsal setae	1	1	1	1
endopodite segment 1 ventral setae	2	2	2	2
endopodite segment 1 dorsal setae	0	0	0	0
endopodite segment 2 ventral setae	1	1	1	1
endopodite segment 2 dorsal setae	1	1	1	1
segment 2 height /length %	47.4%	55.6%	44.1%	35.0%
longest seta % CL	10.4%	8.1%	7.1%	8.5%
longest seta % segment 2	278.9%	461.1%	238.2%	170.0%
longest seta % limb	77.9%	159.6%	52.9%	50.0%
Caudal furca				
paired claws	7 pairs	7 pairs	7 pairs	7 pairs
longest claw % CL	15.2%	14.1%	10.4%	12.0%
unpaired dorsal seta	1 seta	1 seta	1 seta	1 seta

Table 2.6. Male *Euconchoecia* species differences
(n = 1 for each species, %CL = Carapace Length, PDC = posterior dorsal corner).

	chierchiae	*aculeata*	*omanensis*	*hormuzensis*
Carapace				
length	1.26 mm	1.06 mm	1.20 mm	0.98 mm
height	0.70 mm	0.60 mm	0.44 mm	0.40 mm
breadth	0.60 mm	0.46 mm	0.40 mm	0.40 mm
height/length %	55.6%	56.6%	36.7%	40.8%
breadth/length %	47.6%	43.4%	33.3%	40.8%
PDC, left tip to posterior hinge (% CL)	7.5%	0.9%	9.6%	8.7%
PDC, right tip to posterior hinge (% CL)	9.5%	1.9%	12.9%	9.7%
rostrum, left tip to anterior hinge (% CL)	14.3%	21.7%	13.3%	11.7%
rostrum, right tip to anterior hinge (% CL)	14.3%	28.8%	12.9%	9.7%
incisure, left rostrum tip to inner edge (% CL)	15.1%	14.6%	15.0%	12.8%
incisure, right rostrum tip to inner edge (% CL)	12.7%	13.7%	14.6%	11.2%
Frontal organ				
stem and capitulum length (% CL)	23.2%	22.2%	31.3%	21.1%
length relative to antenna 1	shorter	slightly shorter	significantly longer	slightly longer

Table 2.7. Male *Euconchoecia* species differences
(n = 1 for each species, %CL = Carapace Length, n.d. = no data).

	chierchiae	*aculeata*	*omanensis*	*hormuzensis*
Antenna 1				
length segment 2 (% CL)	9.1%	7.1%	10.4%	9.7%
length segment 3 (% CL)	4.8%	8.6%	10.2%	6.4%
length segment 4 (% CL)	3.8%	6.1%	4.6%	3.7%
length segment 5 (% CL)	2.8%	2.8%	3.8%	1.6%
approximate total length	31.0%	32.7%	35.0%	34.0%
bundle setae number	approximately 24	approximately 24	approximately 24	approximately 24
bundle setae length (% CL)	17.5%	n.d.	14.4%	17.1%
a-seta (% CL)	8.3%	n.d.	8.8%	3.7%
b-seta (% CL)	18.1%	n.d.	15.0%	4.6%
c-seta (% CL)	38.9%	n.d.	18.3%	13.8%
d-seta (% CL)	42.5%	n.d.	32.1%	34.2%
e-seta (% CL)	65.1%	n.d.	46.3%	50.0%
Antenna 2				
protopodite (% CL)	38.5%	38.2%	37.1%	40.8%
exopodite 1 (% CL)	17.1%	15.6%	14.0%	15.3%
exopodite 2 - 9 (% exopodite 1)	51.2%	59.1%	58.2%	58.3%
longest swimming seta (% CL)	38.9%	31.6%	34.6%	27.0%
shortest swimming seta (% CL)	3.3%	3.1%	2.5%	1.6%
endopodite segment 1 (% CL)	15.1%	10.7%	14.8%	14.8%
a-seta	1.8%	1.8%	1.6%	1.9%
b-seta	3.8%	1.5%	3.2%	3.7%
endopodite segment 2 (% CL)	5.8%	4.8%	3.8%	5.6%
f-seta (% CL)	22.4%	36.8%	39.2%	39.8%
g-seta (% CL)	79.8%	38.4%	60.0%	119.9%
right clasper shank length	9.1%	1.7%	5.4%	6.4%
h-seta (% CL)	3.4%	1.9%	2.9%	2.8%
i-seta (% CL)	15.9%	16.0%	19.2%	20.7%
j-seta (% CL)	6.3%	9.2%	9.6%	9.7%

Table 2.8. Male *Euconchoecia* species similarities
(n = 1 for each species, %CL = Carapace Length, n.d. = no data).

	chierchiae	*aculeata*	*omanensis*	*hormuzensis*
Mandible				
basale	1 plumose	n.d.	1 plumose	1 plumose
endopodite segment 1 dorsal setae	1	1	1	1
endopodite segment 1 ventral setae	3	3	3	3
endopodite segment 2 dorsal setae	2	2	2	2
endopodite segment 2 ventral setae	1	1	1	1
endopodite segment 3 terminal setae	7	7	7	7
endopodite segment 3 longest claw (% CL)	16.5%	18.2%	16.9%	18.9%
endopodite segment 3 longest claw (% limb)	79.0%	87.5%	96.40%	96.1%
teeth on basal endite	2 + 6	n.d.	2 + 6	2 + 6
pars incisiva	2 + 10	n.d.	2 + 12	2 + 10
distal tooth list	2 + 10	n.d.	2 + 10	2 + 10
proximal list	2 + 5	n.d.	2 + 5	2 + 5
setae laterally on endite	2 + 2	n.d.	2 + 2	2 + 2
exopodite	1 plumose	n.d.	1 plumose	1 plumose
Maxilla				
basal segment anterior setae	5	5	5	5
basal segment lateral setae	1	1	1	1
basal segment posterior setae	4	4	4	4
terminal spines	fine hairs	fine hairs	fine hairs	fine hairs
distal segment claw setae	3	3	3	3
distal segment normal setae	3	3	3	3

Table 2.9. Male *Euconchoecia* species similarities
(n = 1 for each species, %CL = Carapace Length, n.d. = no data).

	chierchiae	*aculeata*	*omanensis*	*hormuzensis*
Fifth limb				
basale ventral setae	2 + 2 + 1	n.d.	2 + 2 + 1	2 + 2 + 1
basale lateral setae	2	n.d.	2	2
basale dorsal setae	1 long	n.d.	1 long	1 long
endopodite segment 1 ventral setae	2	n.d.	2	2
endopodite segment 1 dorsal setae	1	n.d.	1	1
height/lenth %	44.8%	n.d.	53.1%	46.4%
longest terminal seta % CL	4.4%	n.d.	5.6%	6.0%
longest seta/length segment 2	420.0%	n.d.	450.0%	375.0%
longest seta/ length limb	30.1%	n.d.	61.4%	71.4%
Sixth limb				
basale ventral setae	5	5	5	5
basale lateral setae	1	1	1	1
basale dorsal setae	1	1	1	1
endopodite segment 1 ventral setae	2	2	2	2
endopodite segment 1 dorsal setae	0	0	0	0
endopodite segment 2 ventral setae	1	1	1	1
endopodite segment 2 dorsal setae	1	1	1	1
segment 2 height /length %	30.4%	47.5%	35.0%	38.2%
longest seta % CL	28.6%	n.d.	30.4%	34.7%
longest seta % segment 2	313.0%	n.d.	365.0%	400.0%
longest seta % limb	150.0%	n.d.	135.2%	141.7%
Caudal furca				
paired claws	7 pairs	7 pairs	7 pairs	7 pairs
longest claw % CL	18.7%	17.5%	12.5%	14.5%
unpaired dorsal seta	1	1	1	1
Intromittent organ				
length % CL	27.4%	27.4%	19.6%	20.9%

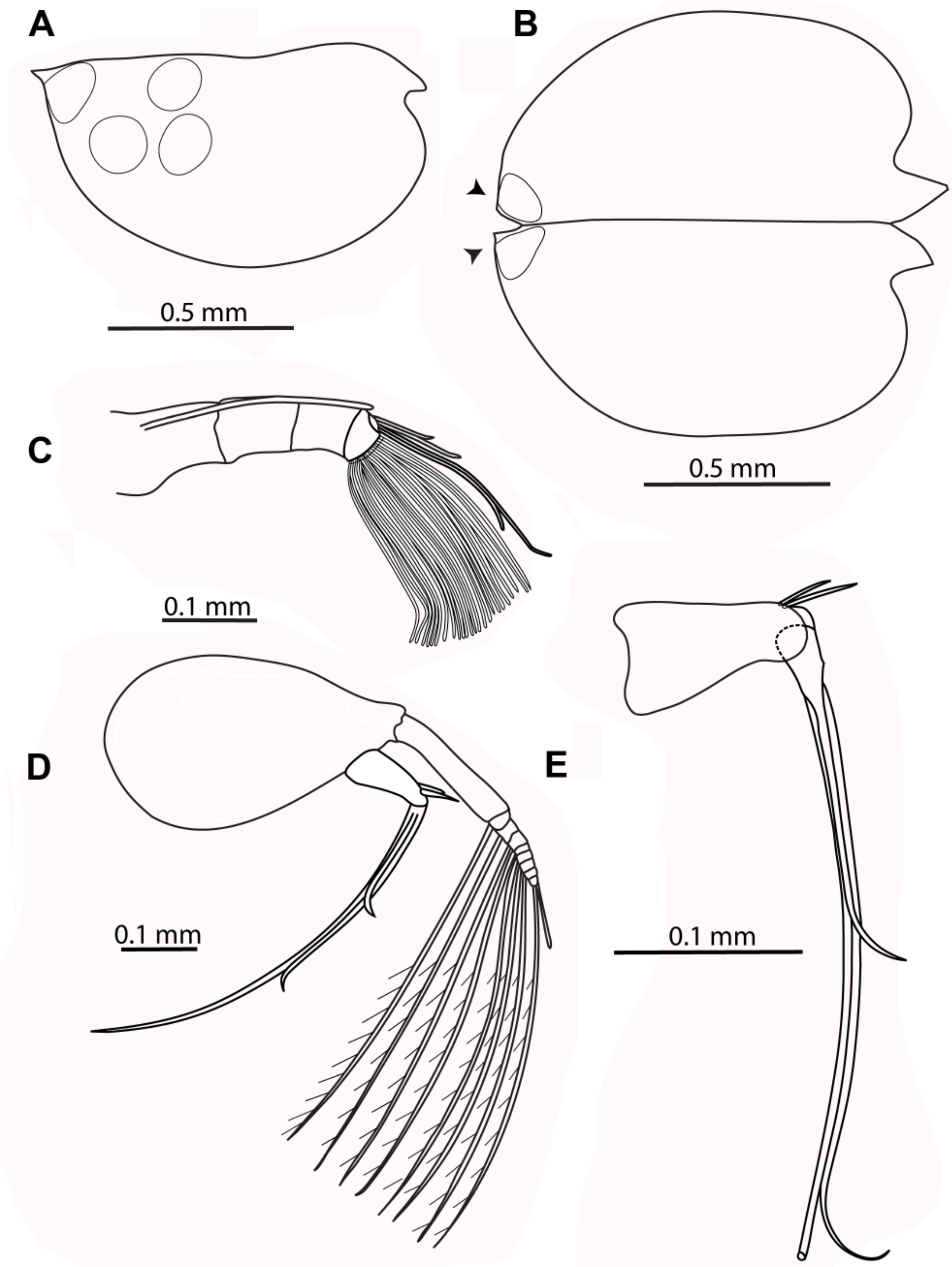


Figure 2.1. *E. chierchiae* female (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside, (E) endopodite viewed from inside.

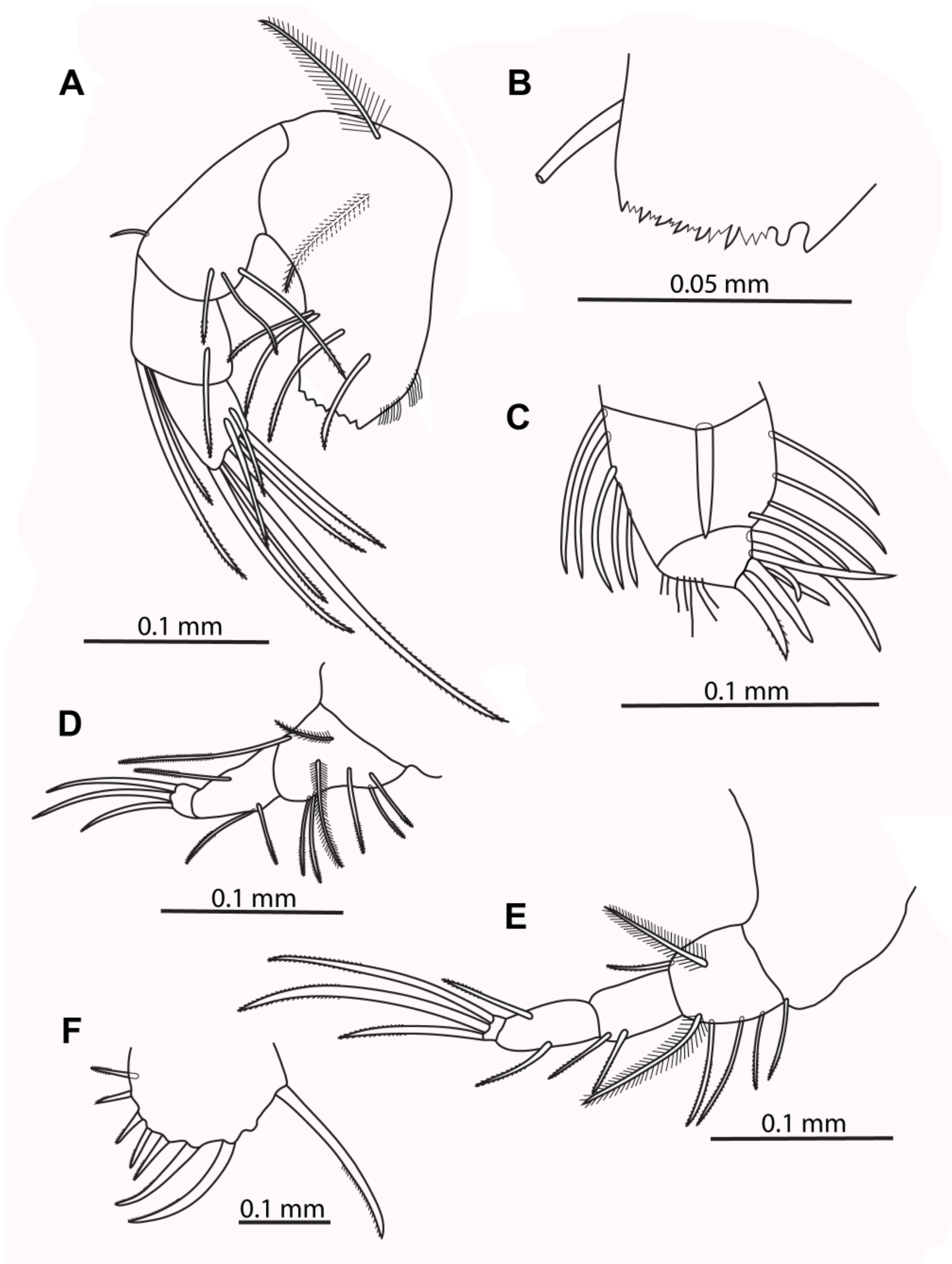


Figure 2.2. *E. chierchiae* female (A) mandible, coxale not shown, (B) basal endite of mandible, (C) maxilla, (D) fifth limb, (E) sixth limb, (F) caudal furca.

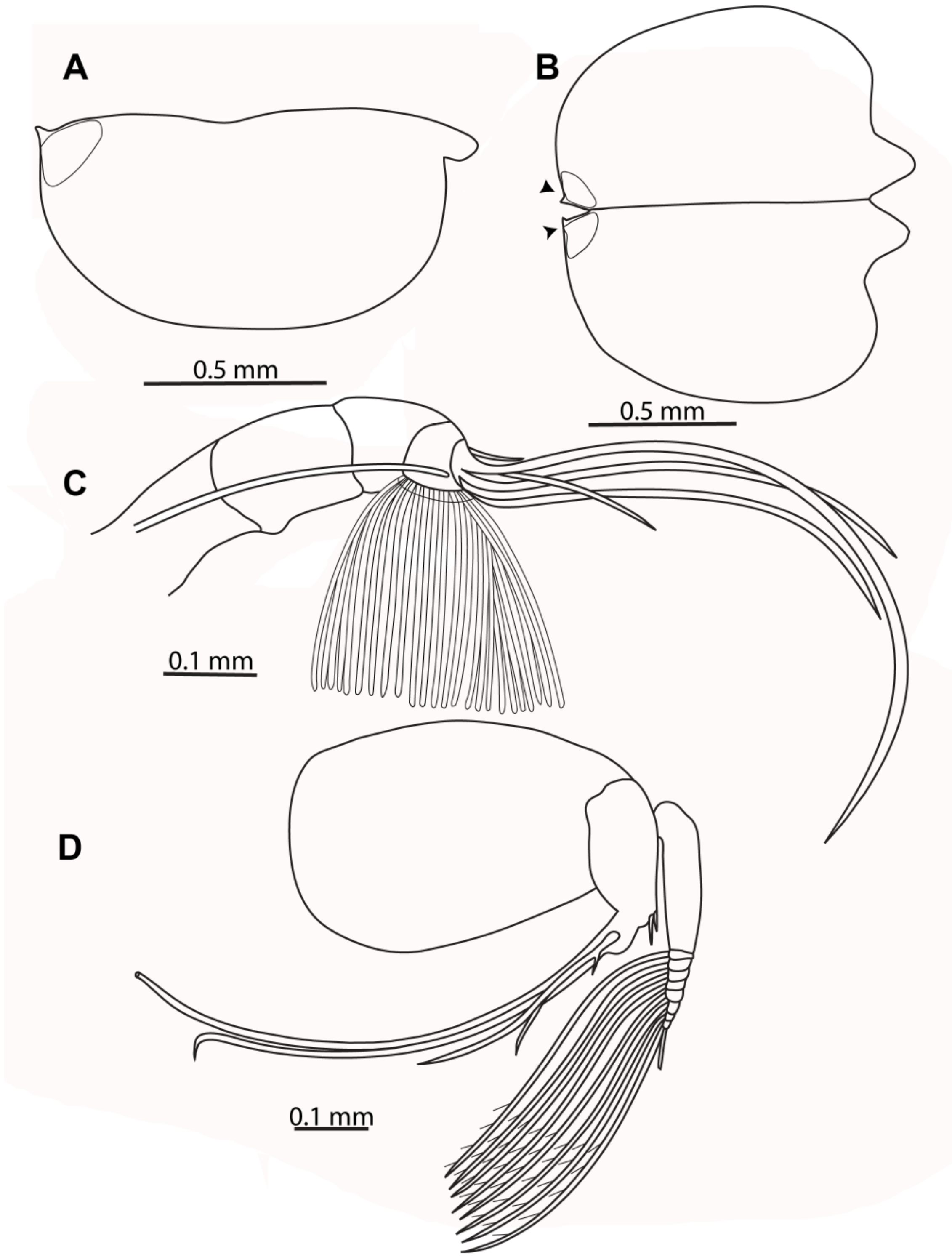


Figure 2.3. *E. chierchiae* male (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside.

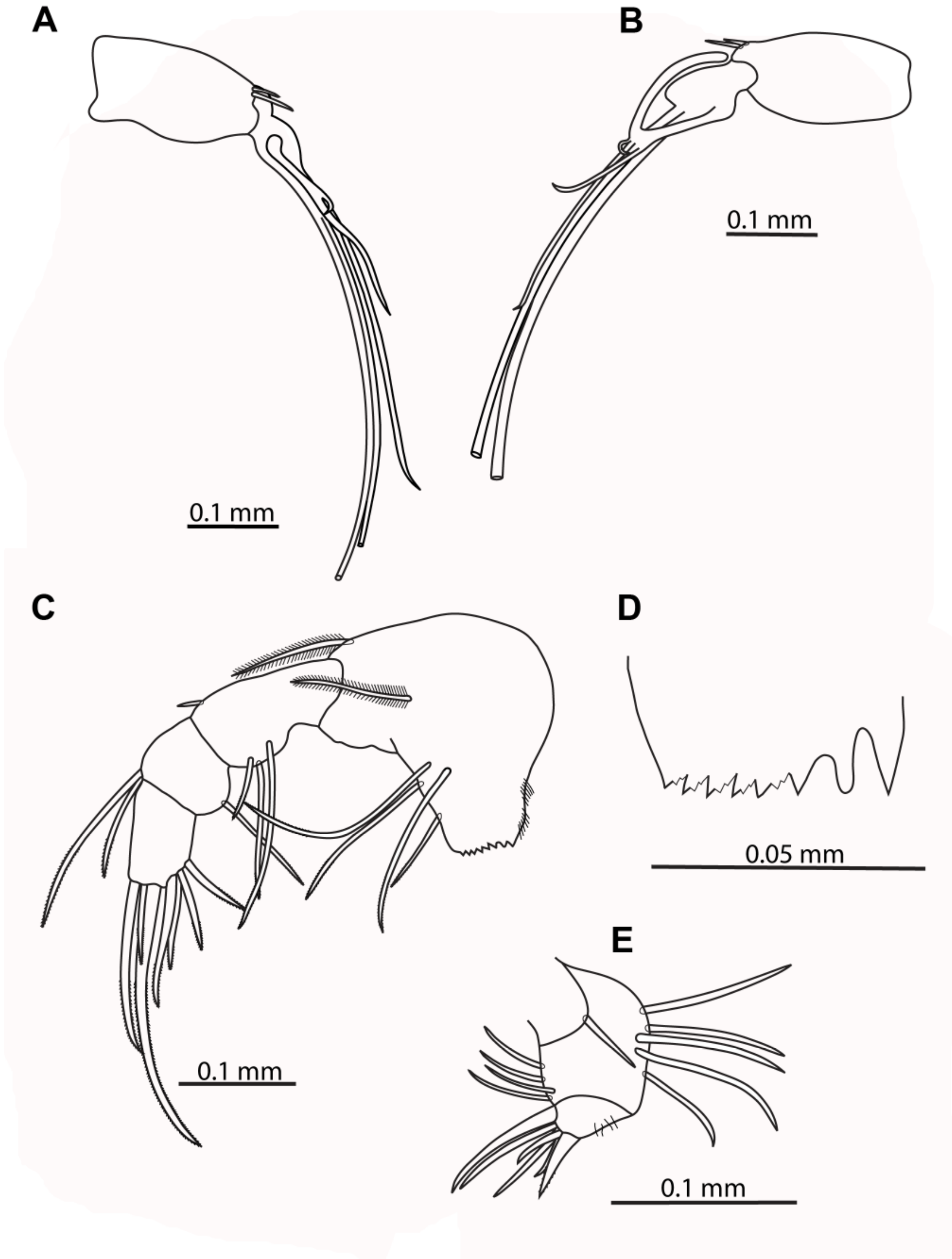


Figure 2.4. *E. chierchiae* male (A) left endopodite viewed from inside, (B) right endopodite viewed from inside, (C) mandible, coxale not shown, (D) basal endite of mandible, (E) maxilla.

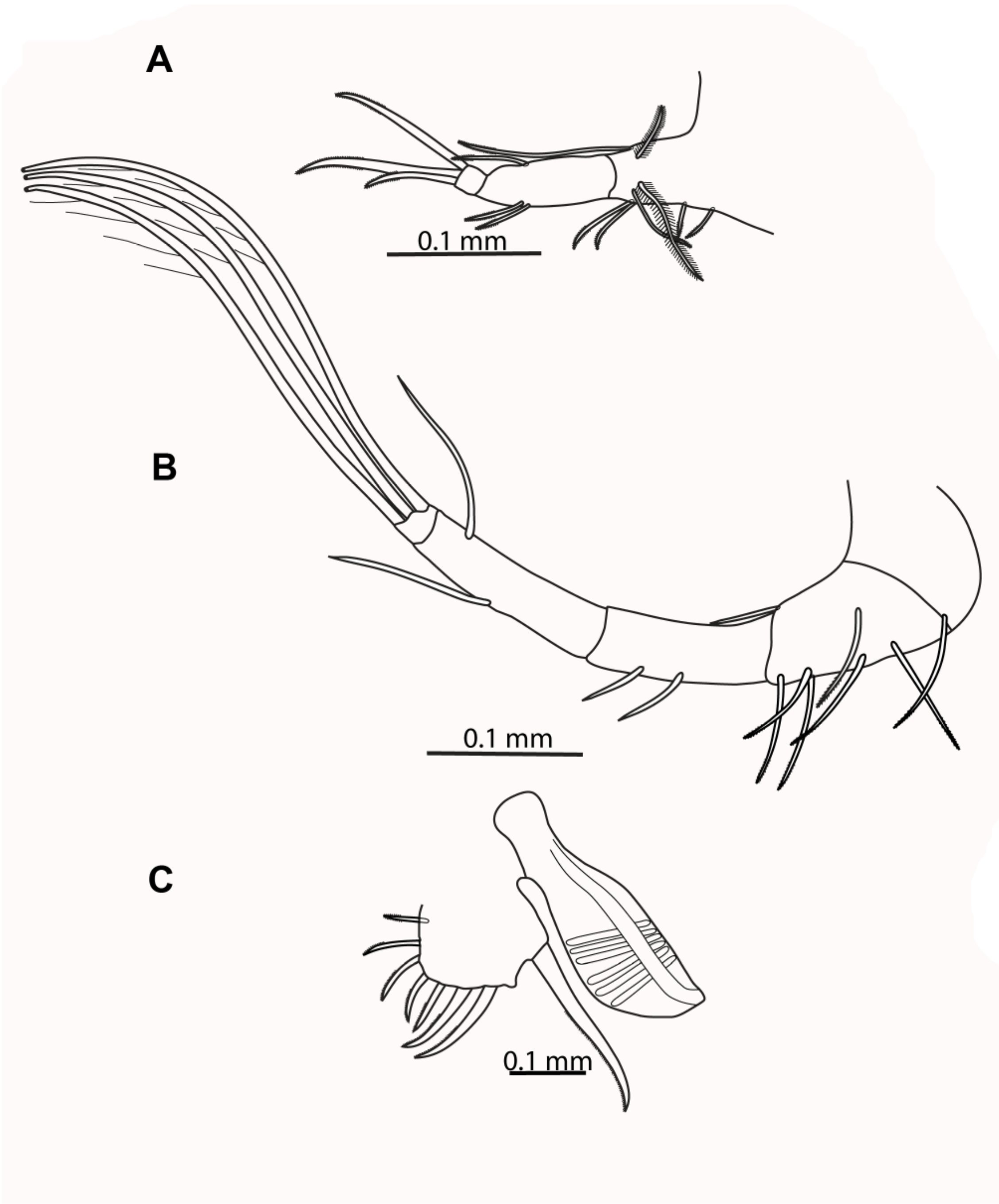


Figure 2.5. *E. chierchiae* male (A) fifth limb, (B) sixth limb, (C) caudal furca and intromittent organ.

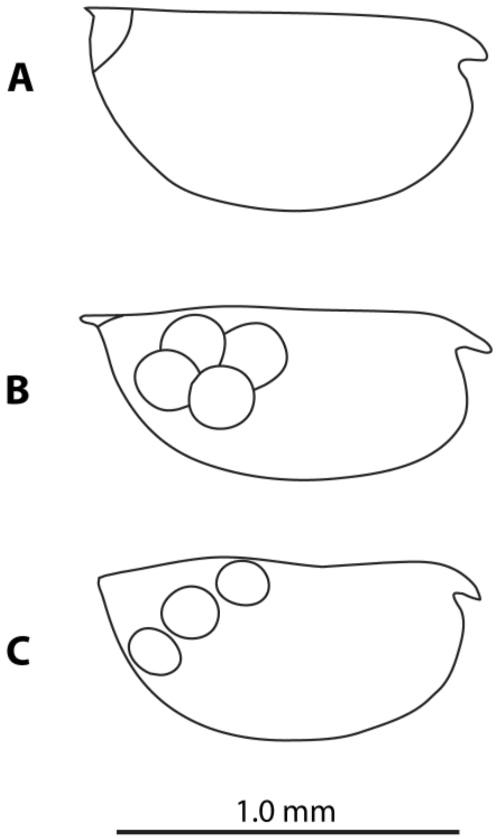


Figure 2.6. *Euconchoecia chierchiae* (A) as drawn by Müller (1906) female 1.15 – 1.57 mm, (B) as drawn by Skogsberg (1920) female 1.10 – 1.30 mm, (C) as drawn by Angel (1993) female 1.08 – 1.30 mm.

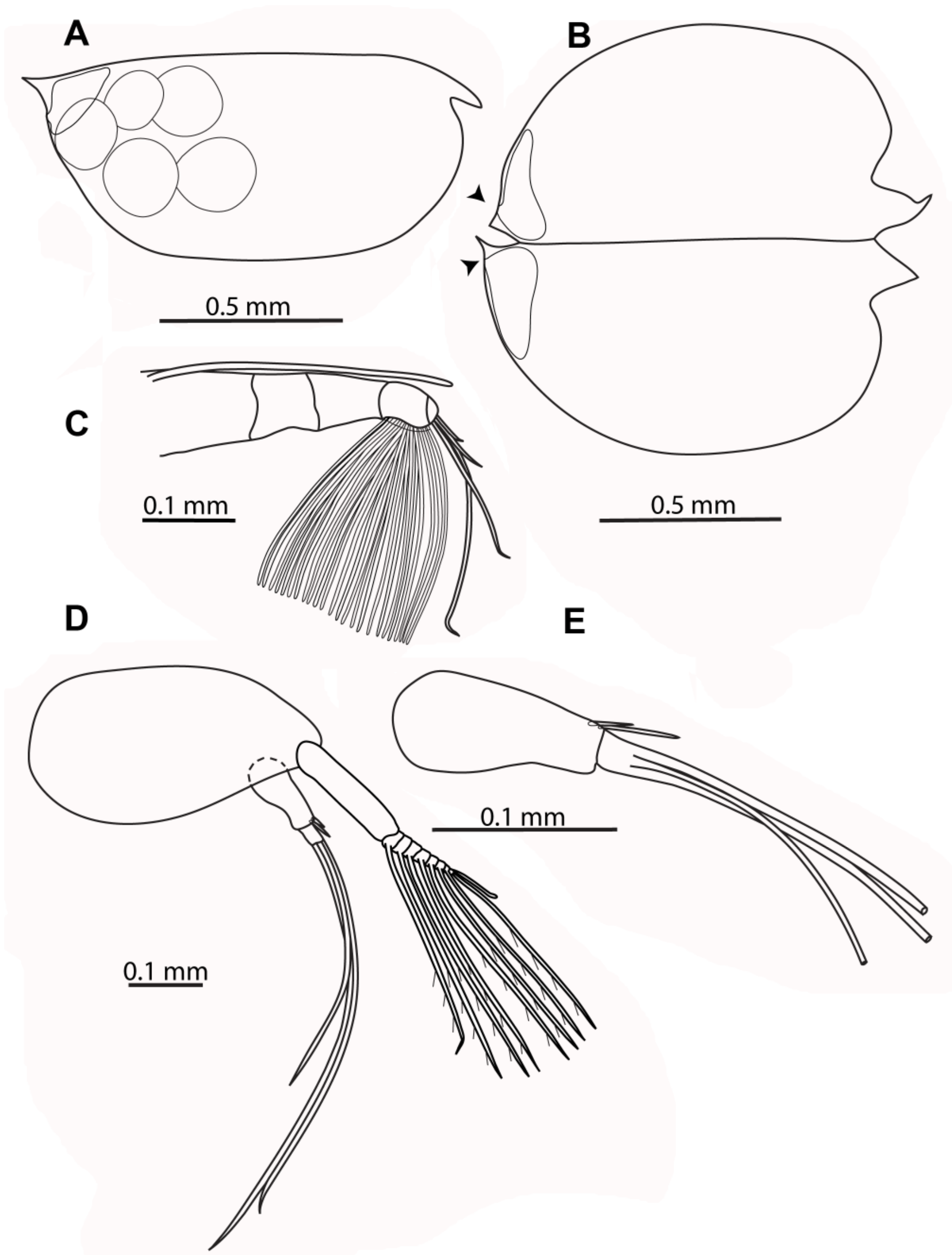


Figure 2.7. *E. aculeata* female (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside, (E) endopodite viewed from inside.

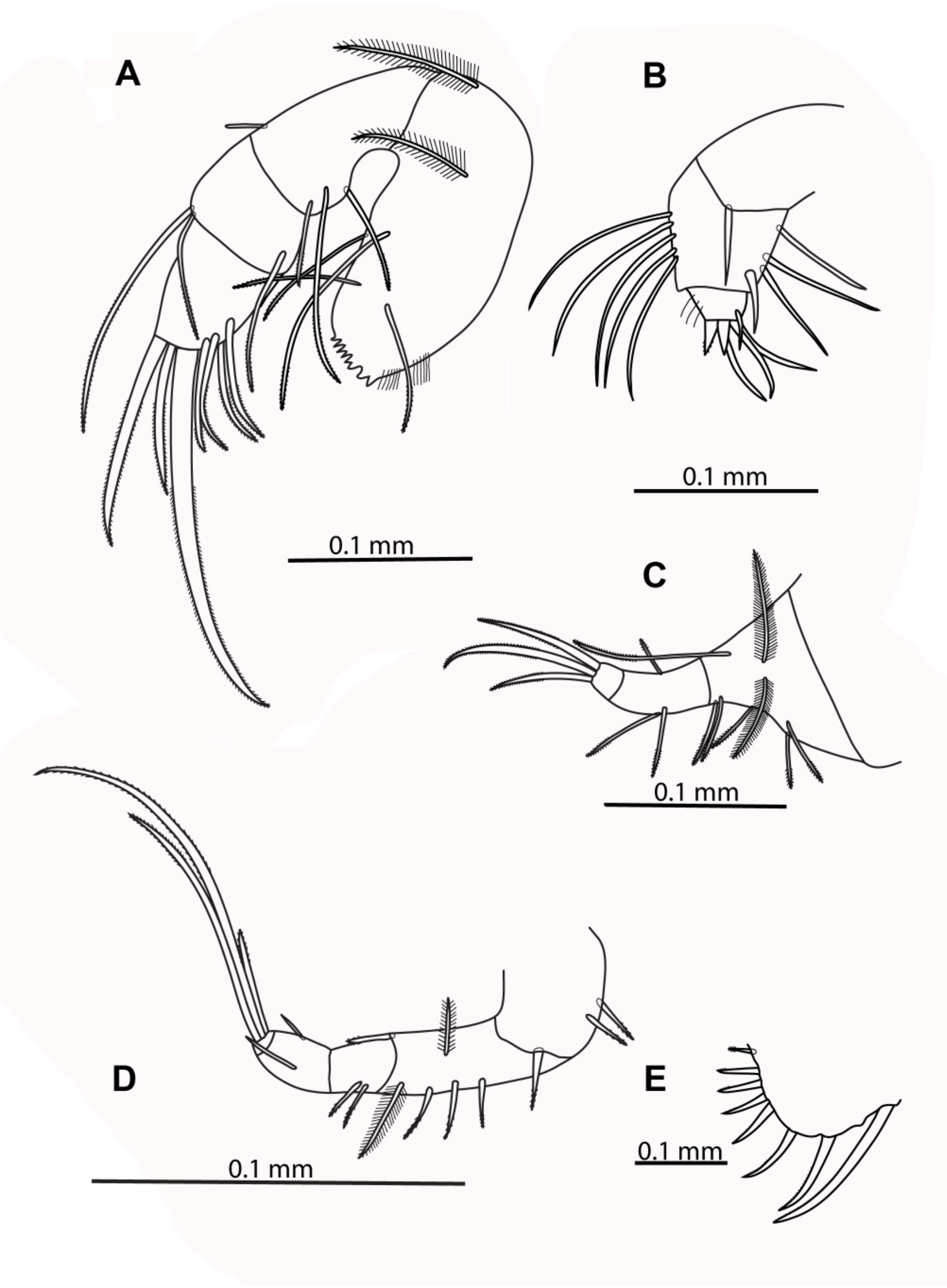


Figure 2.8. *E. aculeata* female (A) Mandible, coxale not shown, (B) maxilla, (C). fifth limb, (D) sixth limb, (E) caudal furca.

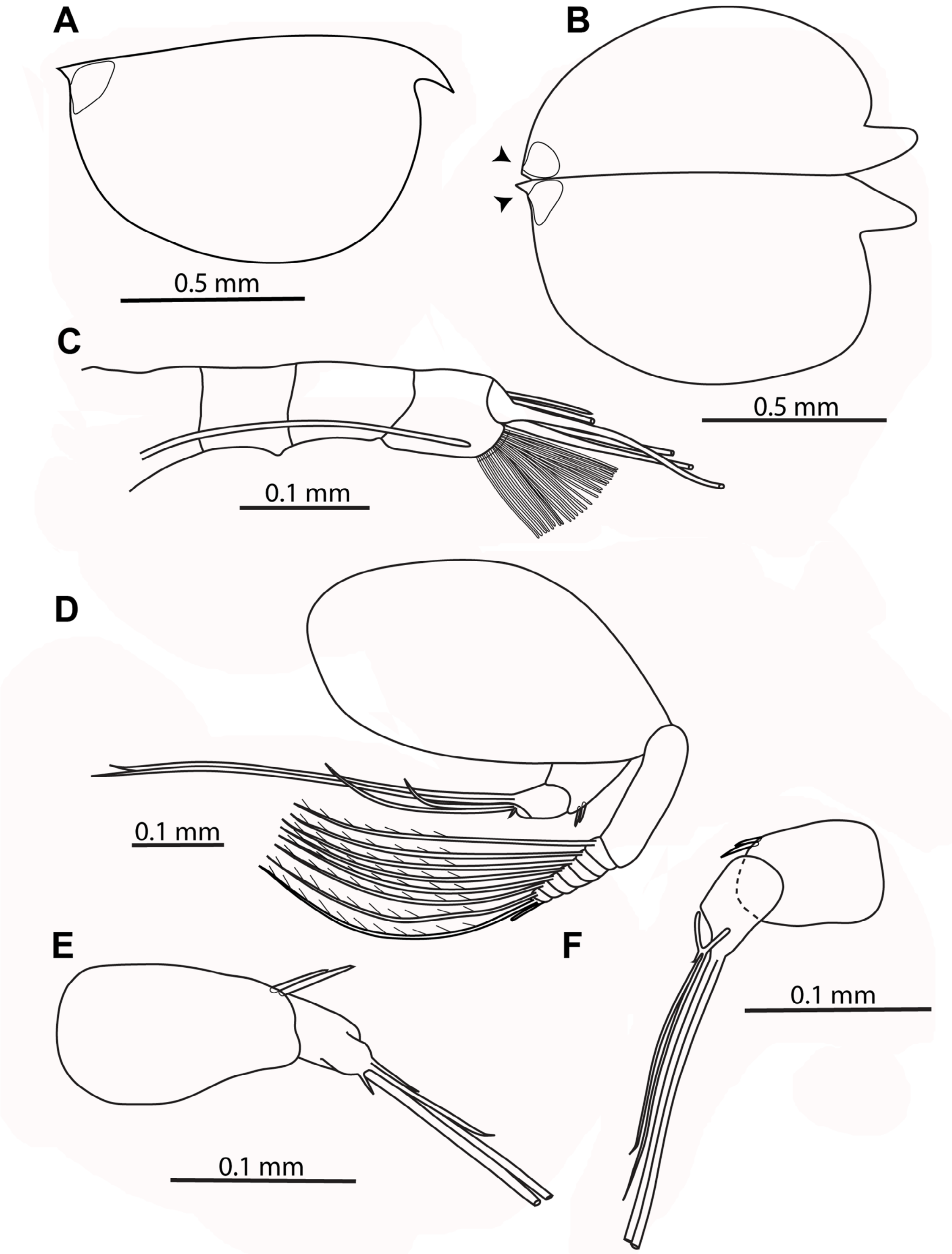


Figure 2.9. *E. aculeata* male (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside, (E) left endopodite viewed from inside, (F) right endopodite viewed from inside.

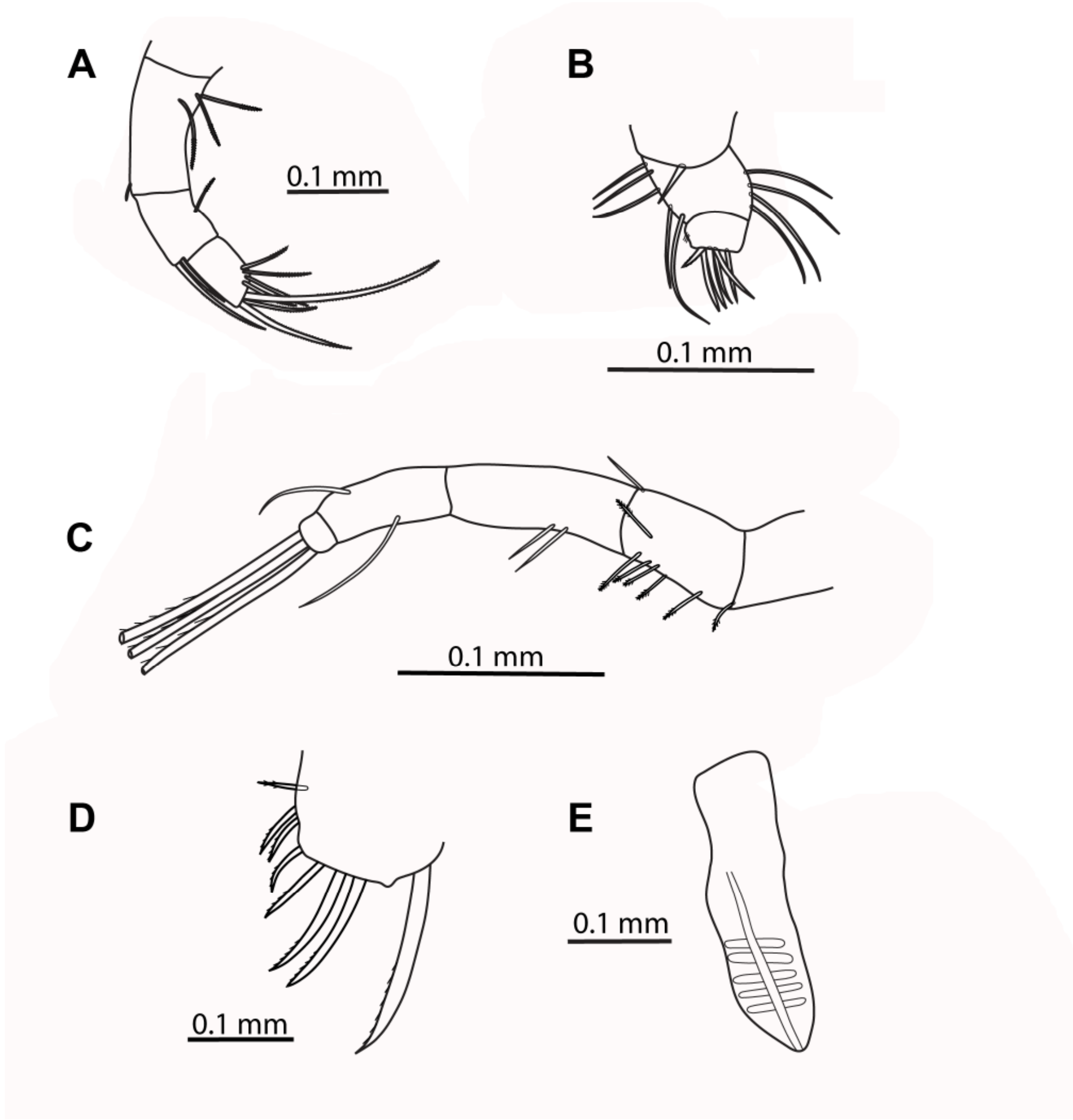


Figure 2.10. *E. aculeata* male (A) mandible, coxale not shown, (B) maxilla, (C) Sixth limb, (D) caudal furca, (E) intromittent organ.

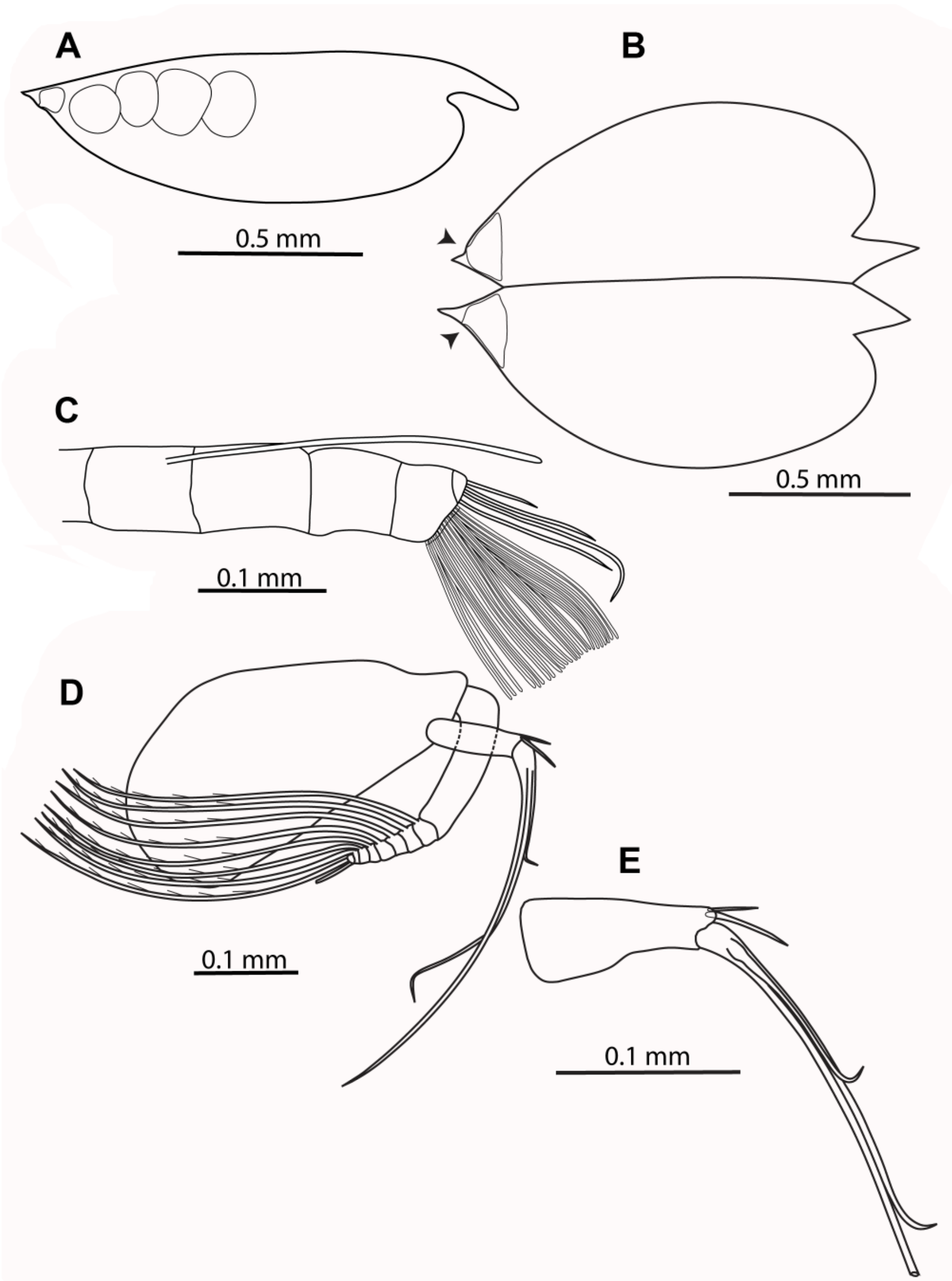


Figure 2.11. *E. omanensis* female (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside, (E) endopodite viewed from inside.

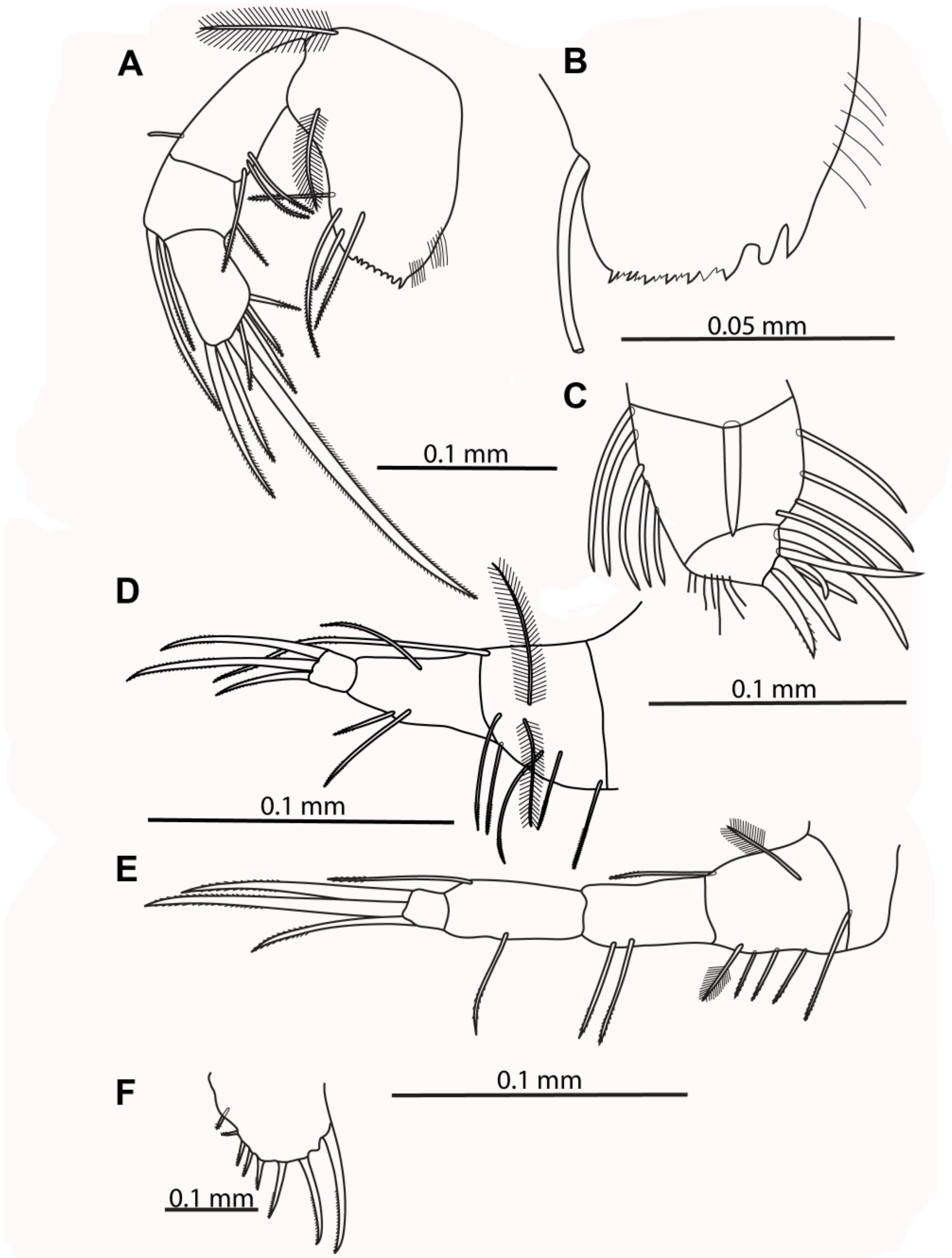


Figure 2.12. *E. omanensis* female (A) mandible, coxale not shown, (B) basal endite of mandible, (C) maxilla, (D) fifth limb, (E) sixth limb, (F) caudal furca.

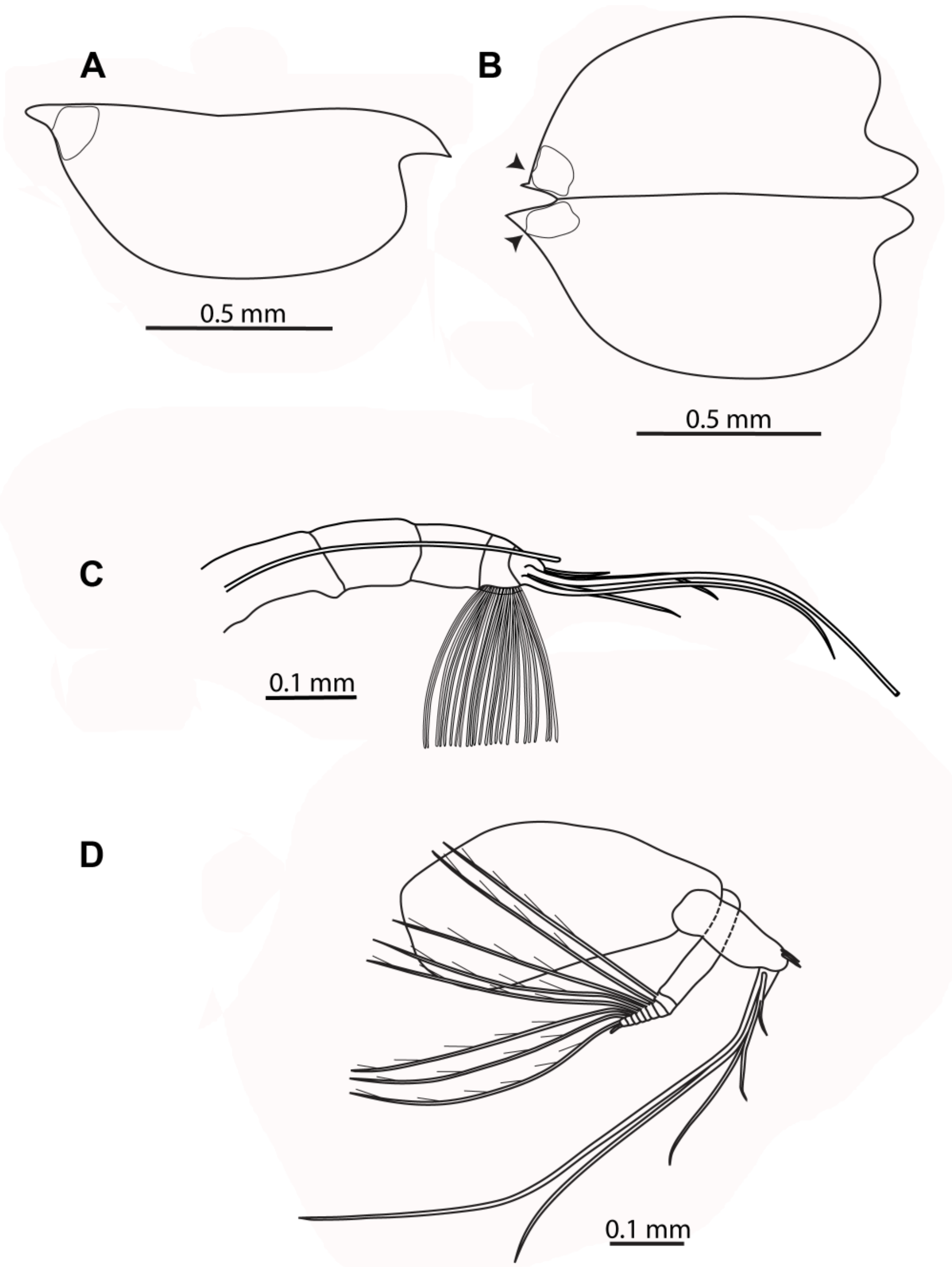


Figure 2.13. *E. omanensis* male (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (**C)** frontal organ and first antenna, (D) second antenna viewed from inside.

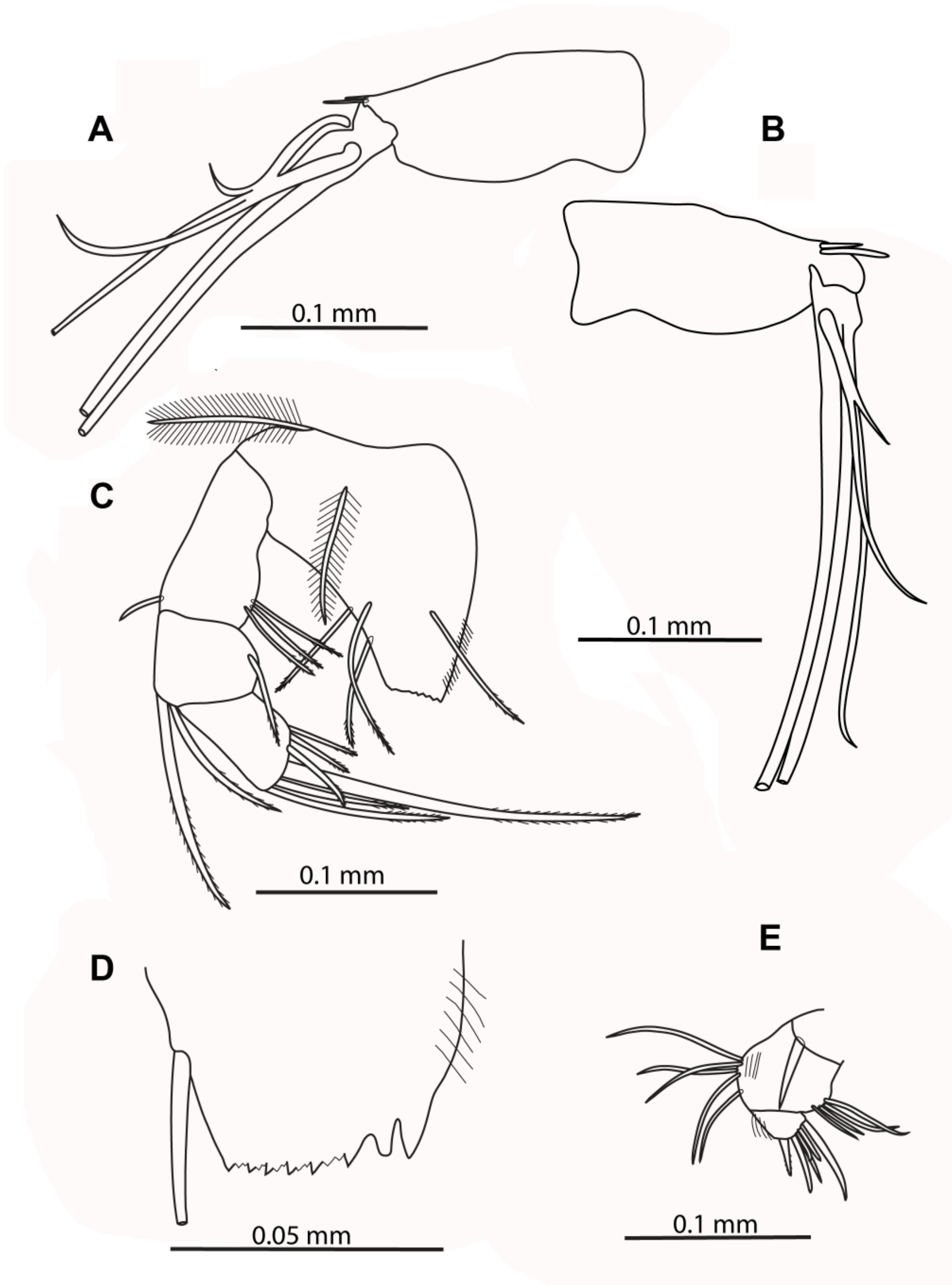


Figure 2.14. *E. omanensis* male (A) right endopodite viewed from inside, (B) left endopodite viewed from inside, (C) mandible, coxale not shown, (D) basal endite of mandible, (E) maxilla.

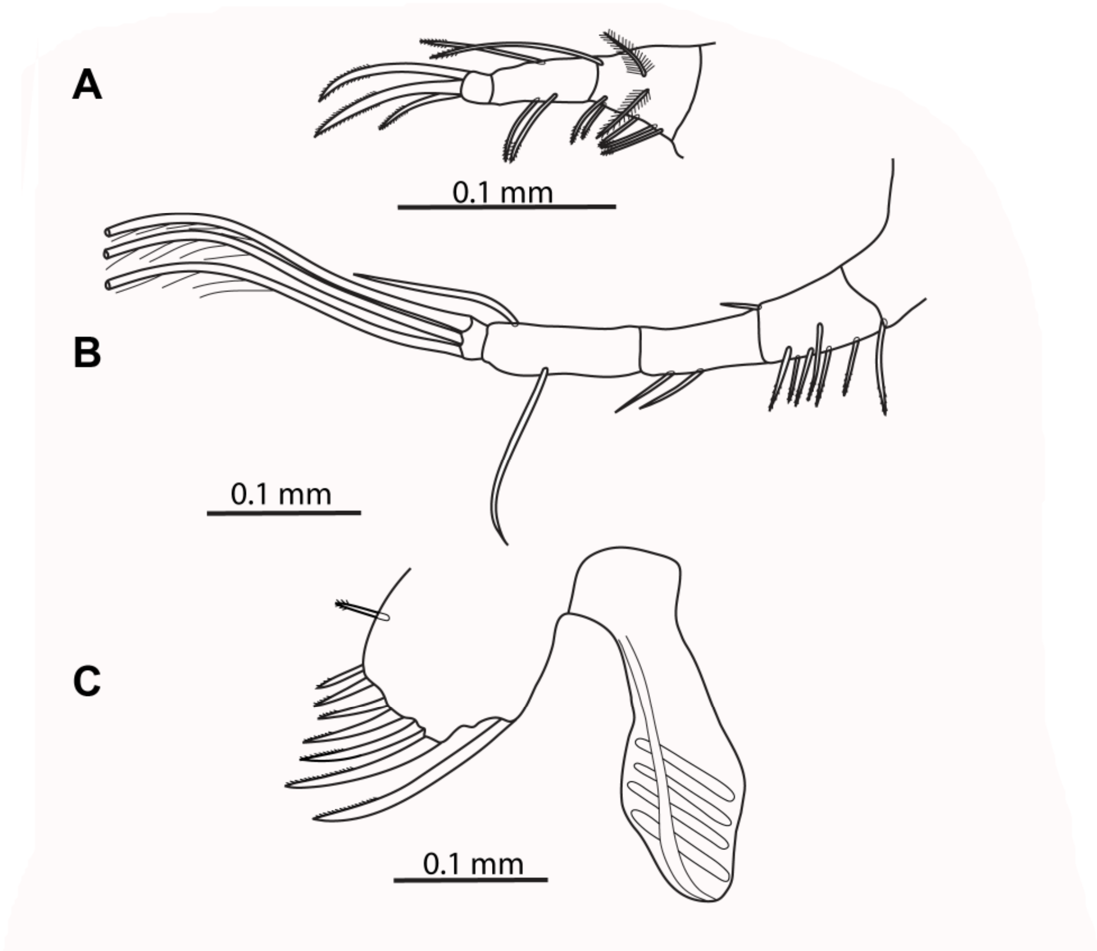


Figure 2.15. *E. omanensis* male (A) fifth limb, (B) sixth limb, (C) caudal furca and intromittent organ.

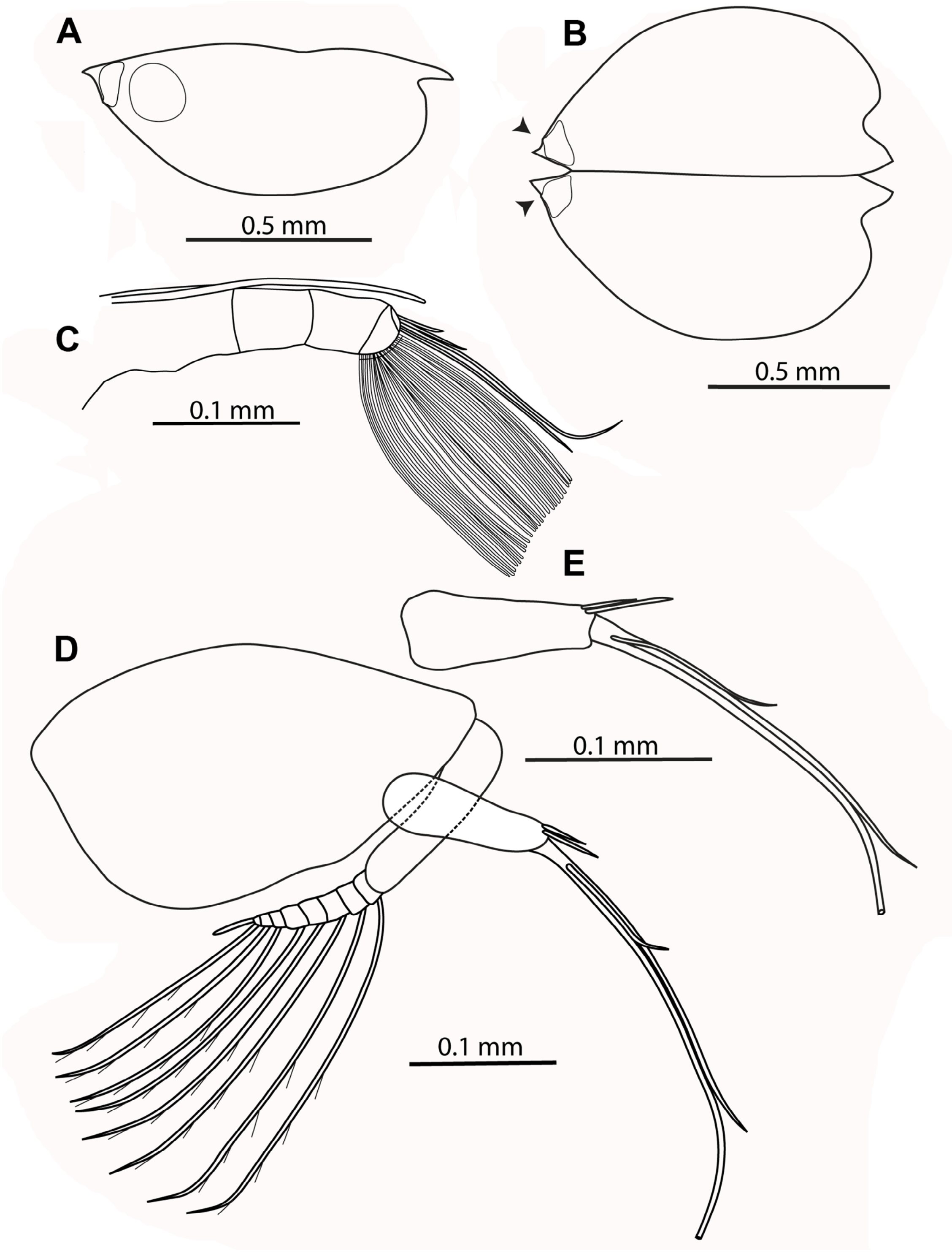


Figure 2.16. *E. hormuzensis* female (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside, (E) endopodite viewed from inside.

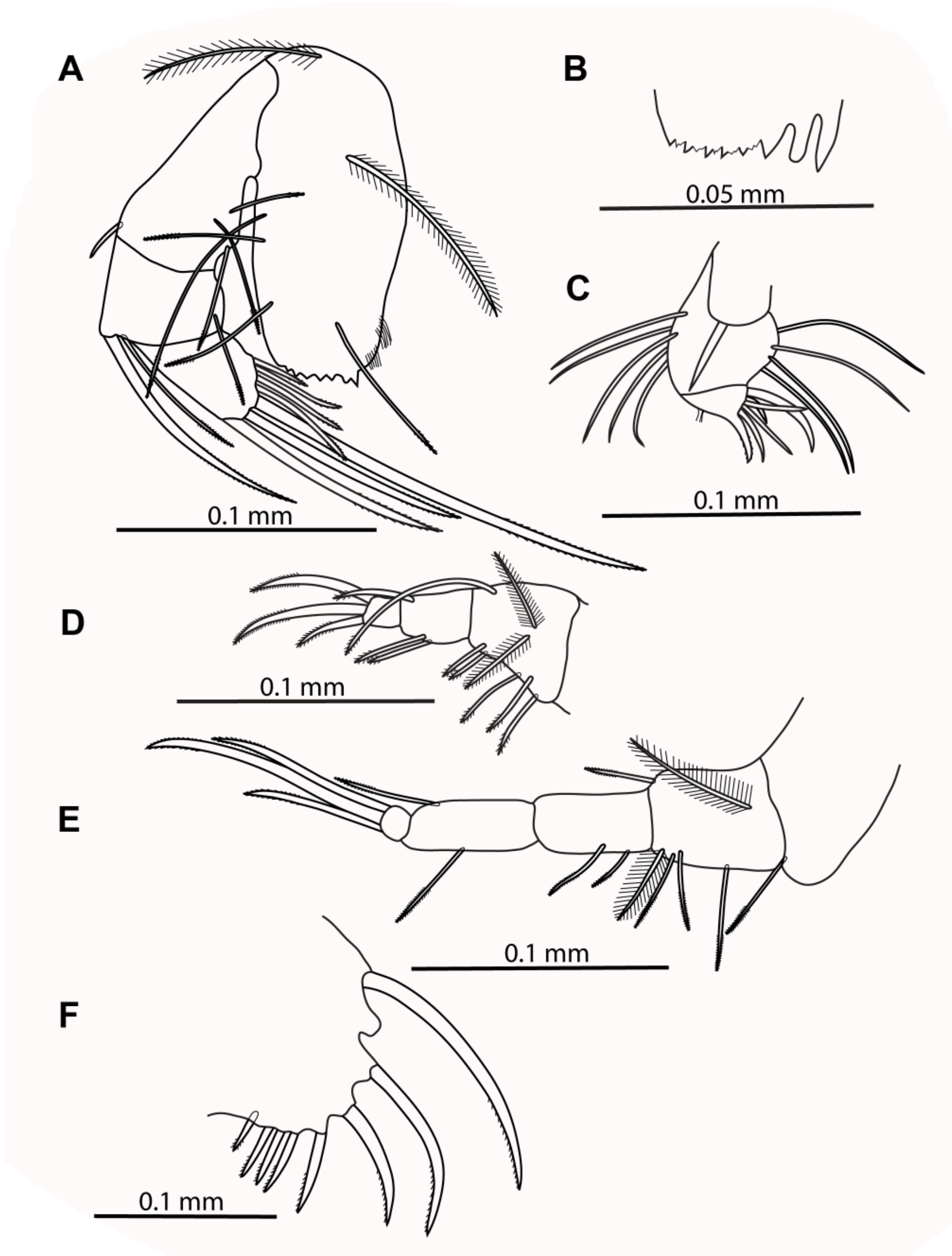


Figure 2.17. *E. hormuzensis* female (A) mandible, coxale not shown, (B) basal endite of mandible, (C) maxilla, (D) fifth limb, (E) sixth limb, (F) caudal furca.

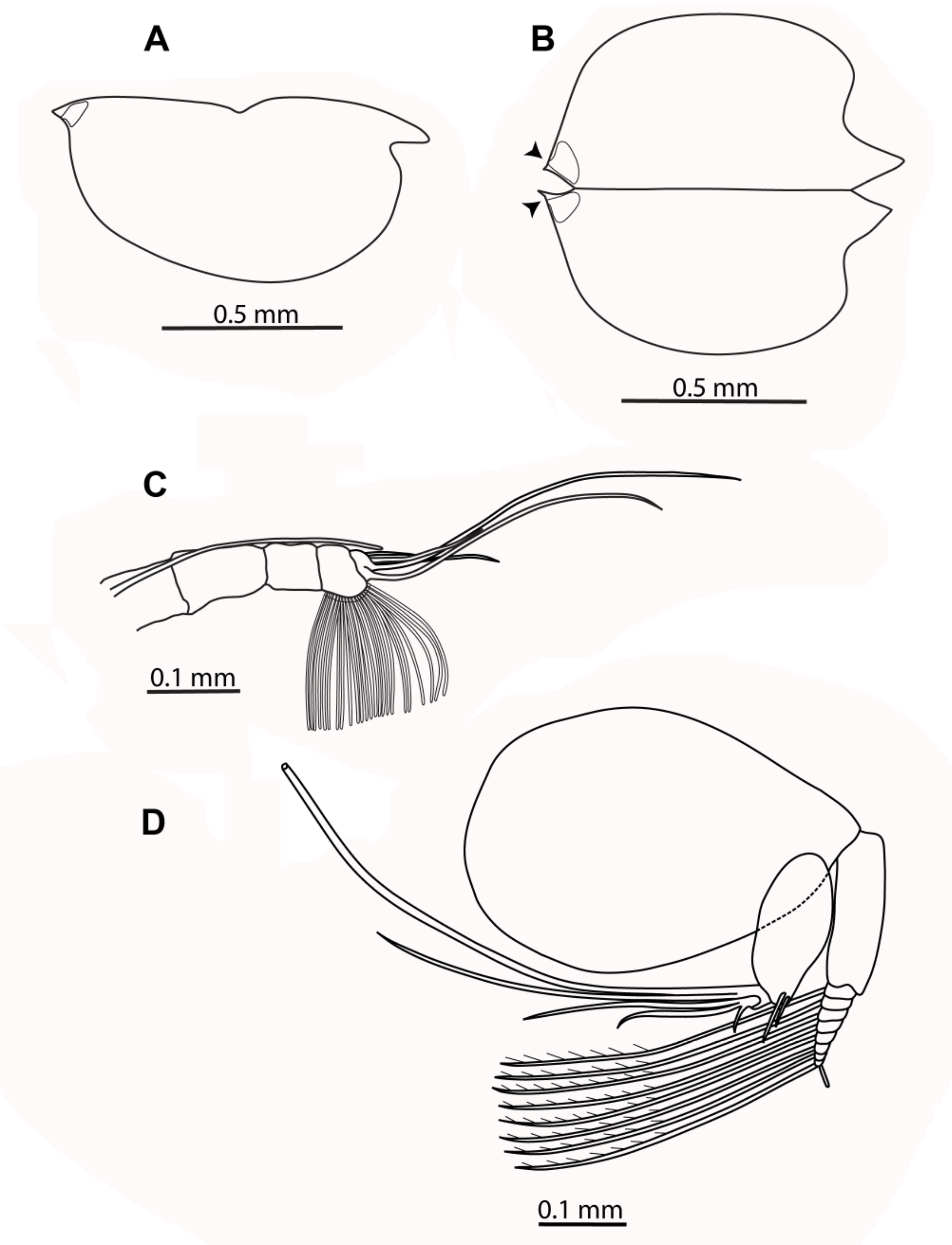


Figure 2.18. *E. hormuzensis* male (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside.

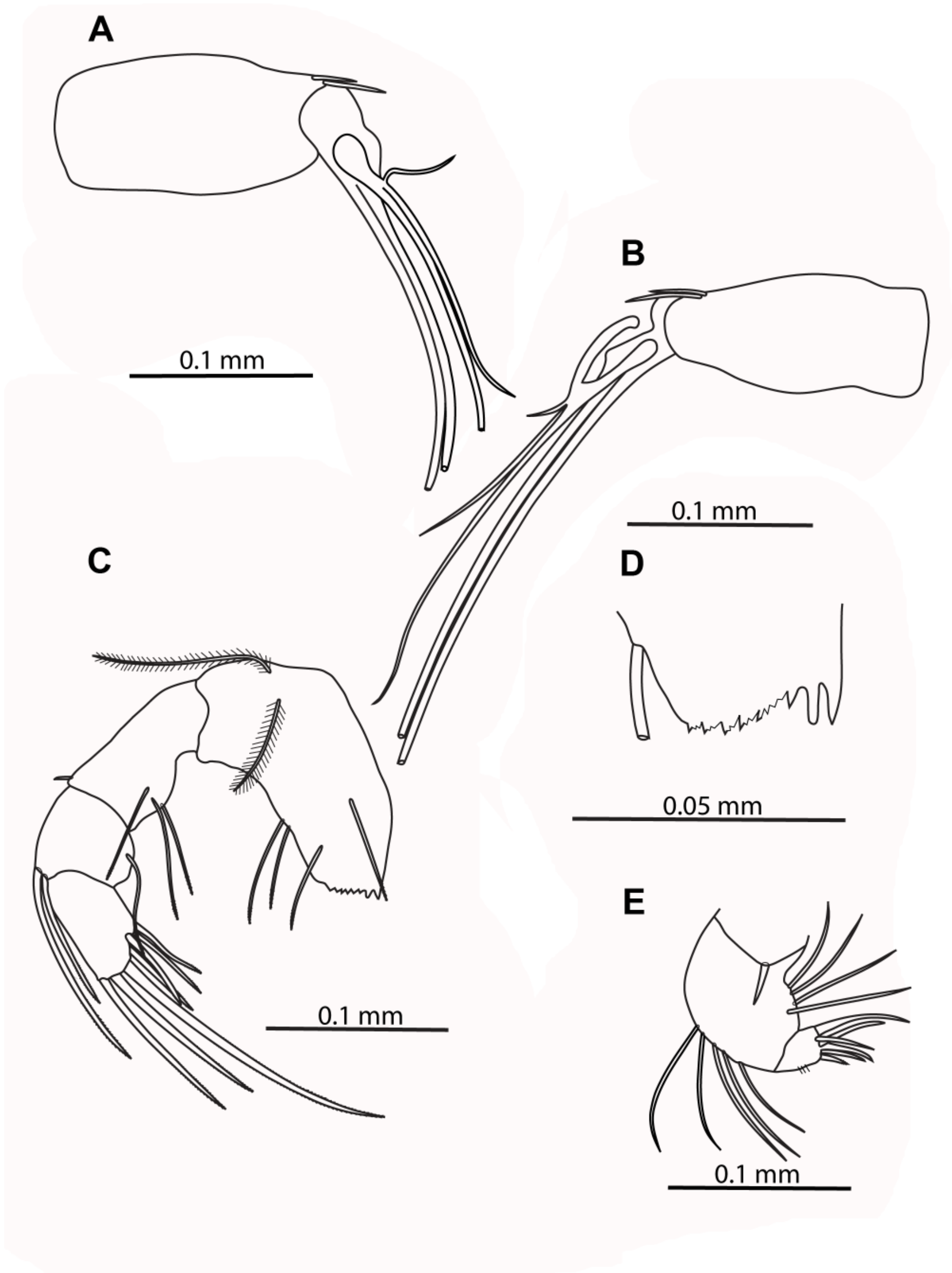


Figure 2.19. *E. hormuzensis* male (A) left endopodite viewed from inside, (B) right endopodite viewed from inside, (C) mandible, coxale not shown, (D) basal endite of mandible, (E) maxilla.

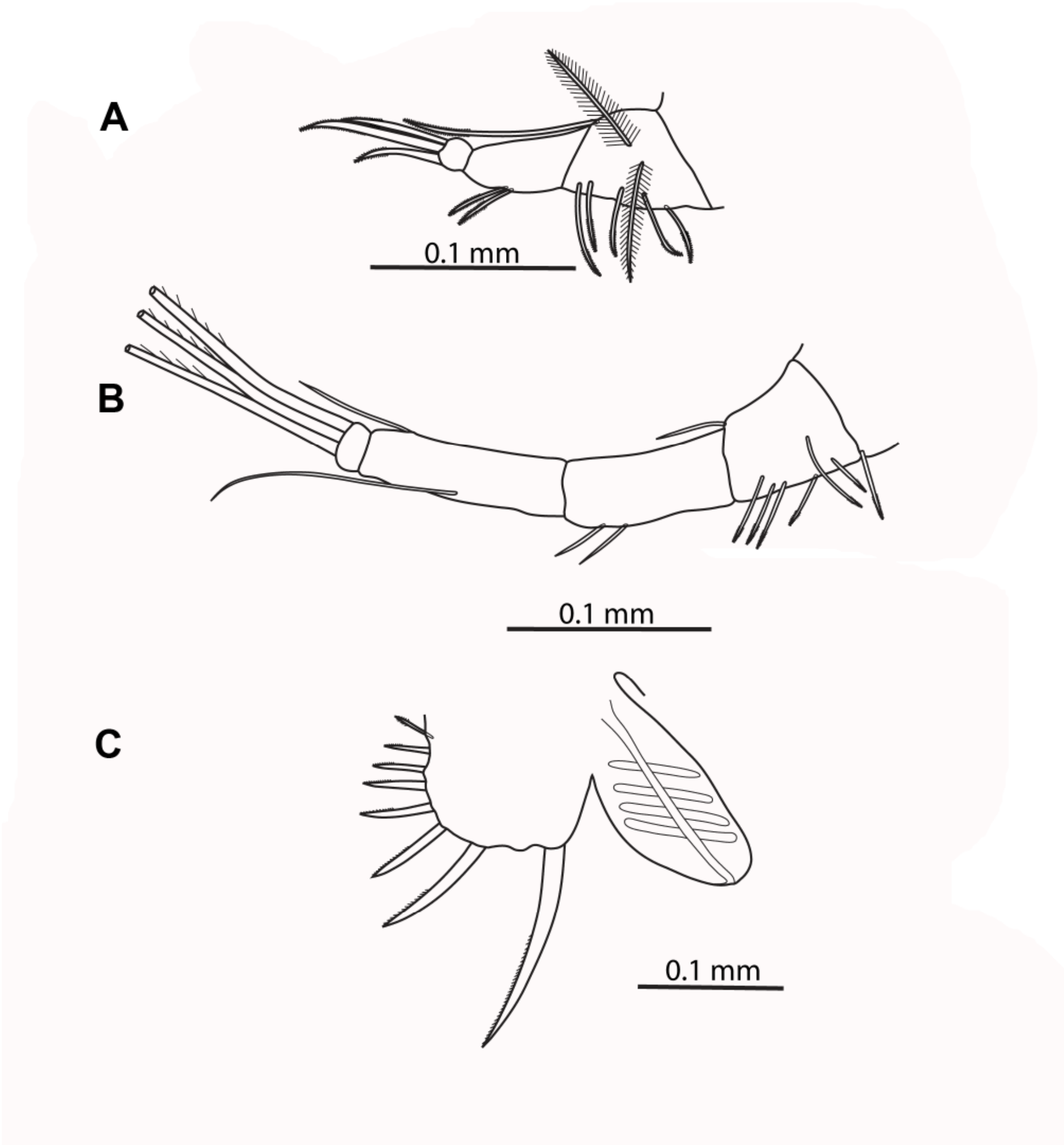


Figure 2.20. *E. hormuzensis* male (A) fifth limb, (B) sixth limb, (C) caudal furca and intermittent organ.

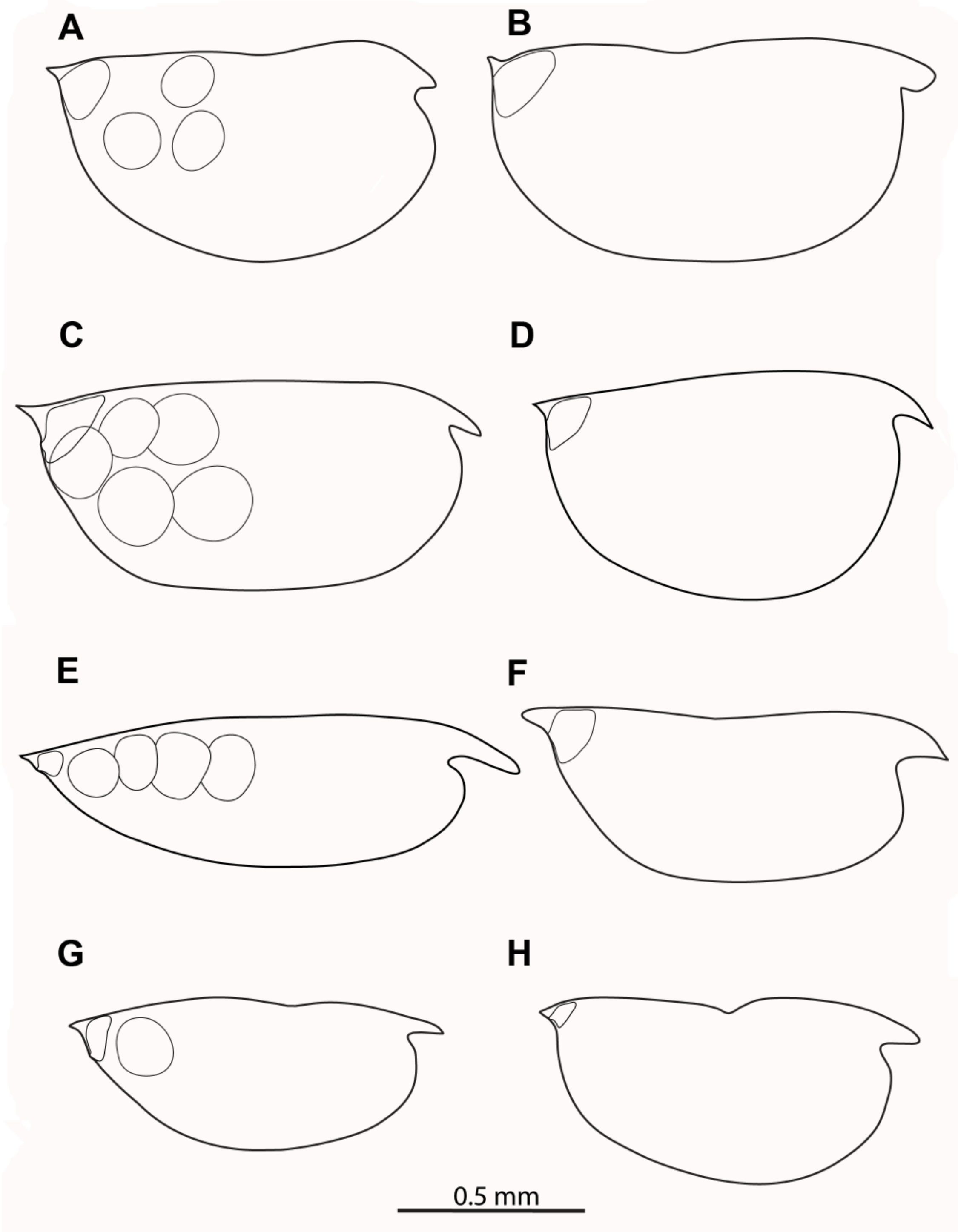


Figure 2.21. *Euconchoecia* (A) *E. chierchiae* female, (B) *E. chierchiae* male, (C) *E. aculeata* female, (D) *E. aculeata* male, (E) *E. omanensis* female, (F) *E. omanensis* male, (G) *E. hormuzensis* female, (H) *E. hormuzensis* male, all viewed laterally and showing developing embryos inside females.

2.13 References

Angel MV. 1979. Studies on Atlantic halocyprid ostracods: their vertical distributions and community structure in the central gyre region along latitude 30°N from off Africa to Bermuda. Progress in Oceanography, 8, 1-122.

Angel MV. 1999. Ostracoda. In: Boltovskoy D, ed. South Atlantic Zooplankton, Backhuys Publishers, Leiden, The Netherlands, pp. 815-868.

Angel MV. Blachowiak-Samolyk, K., 2006. *Obtusoecia* (Halocyprida: Myodocopa: Ostracoda) a bipolar planktonic oceanic genus: taxonomy, bathymetry and zoogeographical distribution. Annales Zoologici (Warszawa), 2006, 56 (1): 1–48.

Baker JH. Jones TL. Salinas J. 1977. Occurrence of Euconchoecia chierchiae,

Muller, 1890, (Ostracoda, Halocyprididae) in Cedar Bayou, Chambers County, Texas. Chesapeake Science, 18, 4, 394

Boxshall GA. 1998. Comparative limb morphology in major crustacean groups: the coxal-basis joint in post-mandibular limbs. In: Fortey RA, & Thomas RH, eds. Arthropod Relationships, Systematics Association special volume, Series 55, Chapman and Hall, London, 155-167.

Brady GS. 1902. On new or imperfectly known Ostracoda, chiefly from a collection in the Zoological Museum, Copenhagen. Transactions of the Zoological Society of London, 16, 179–210.

Chavtur VG. 1976. Fauna of pelagic ostracods of the far-eastern seas of the USSR. In: Coastal biocenoses of the Far Eastern Seas of the USSR, Nauk, Vladivostok, 99-109.

Chen, R. Lin J. 1984. A new species of *Euconchoecia* from the East China Sea. Acta Oceanologica Sinica, 5 supplement, 859-861.

Cleve PT. 1900. The seasonal distribution of Atlantic plankton organisms, Göteborg, 1900, 38-40.

Cleve PT. 1905. The plankton of the South African Seas. III Halocyprididae. Marine Investigations in South Africa, 4, 129-132.

Da Rocha CEF. 1983. Distribution of *Euconchoecia* G.W.Müller (Crustacea, Ostracoda) off Santos Brazil. Boletim de Zoologia, 6, 53-61.

Deevey GB. 1968. Pelagic ostracods of the Sargasso Sea off Bermuda. Bulletin of the Peabody Museum of Natural History, 26, 1-125.

Deevey GB. 1970. Pelagic ostracods (Myodocopa, Halocyprididae) from the North Atlantic off Barbados. Proceedings of the Biological Society of Washington, 82, 799 - 824.

George J. 1977. Studies on planktonic ostracods of the Northern Indian Ocean. PhD. Thesis, University of Cochin.

Herring PJ. Howell PR. Roe HSJ. 1998. Scheherezade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb – 30 Apr 1997. No11. Biomass data. Leg 1, 12 Feb – 19 Mar 1997. (Unpublished manuscript).

Herring PJ. Howell PR. Pugh PR. 1999. Scheherezade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb – 30 Apr 1997. No 16, Fish, decapod shrimps and siphonophores: abundances and size data. Leg1. 12 Feb – Mar 1997. (Unpublished manuscript).

Kornicker LS. 2003. Morphology and musculature of the fifth and sixth limbs of Halocyprida (Ostracoda-Myodocopa). Journal of Crustacean Biology, 23, 765-776.

Müller GW. 1890. Ueber Halocypriden. Zoologische Jahrbücher 5, 211-252.

Müller GW. 1906. Ostracoda. Wissenschaftliche Ergebnisse der Deutschen Tiefsee-Expedition ‘*Valdivia’* 1989 – 1899, 8, 29–154.

Müller GW. 1912. Ostracoden. Das Tierreich, 31, 1–434.

Poulsen EM. 1969. Ostracoda-Myodocopa. 3a. Halocypriformes-Thaumatocypridae and Halocypridae. Dana Report, 75, 1–100.

Roe HSJ. Shale DM. 1979. A new multiple rectangular midwater trawl (RMT1+8) and some modifications to the Institute of Oceanographic Sciences’ RMT1+8. Marine Biology, 50, 283–288.

Roe HSJ. Baker AdeC. Carson RM. Wild RA. Shale DM. 1980. Behaviour of the Institute of Oceanographic Sciences’ rectangular midwater trawls; theoretical aspects and experimental observations. Marine Biology, 56, 247-259.

Scott T. 1894. Report on Entomostraca from the Gulf of Guinea collected by John Rattray BSc. Transactions of the Linnean Society, London, Series 2, 6, 1-16.

Skogsberg T. 1920. Studies on marine ostracods. Part 1. (Cypridinids, halocyprids and polycopids). Zoologiska Bidrag Fran Uppsala, Supplement 1, 1–784.

Tseng WY. 1969. *Euconchoecia* (Ostracoda) from Taiwan Straits. Reports of the Taiwan Laboratory of Fish Biology, 19, 1-26.

Tseng WY. 1975. Biology of the pelagic ostracod, *Euconchoecia elongata* Müller. Reports of the Taiwan Laboratory of Fish Biology, 27, 1-183.

Vavra V. 1906. Die Ostracoden (Halocypriden und Cypridiniden) der Plankton-Expedition. Ergebnisse der Plankton-Expedition der Humboldt-Stiftung, 2, 1-76.

<u>Chapter 3</u> (Published as Graves, C (2012) J. Nat. Hist. 46: 516-556)

Mamilloecia indica **(Halocyprididae, Ostracoda) a new genus and species from the Northwest Indian Ocean**

3.1 Abstract

A stratified zooplankton sample series taken from the upwelling region of the Gulf of Oman during February 1997 was analysed. Samples collected from below 1500 m contained an abundant species that closely resembled *Paraconchoecia mamillata* Müller, 1906 found in the Atlantic. Morphological and statistical analysis showed that the Oman species differed significantly from *P. mamillata*. In addition both species differed significantly from *Paraconchoecia spinifera*, the type species of the genus *Paraconchoecia*. A new genus, *Mamilloecia,* is erected to accommodate both the Oman and Atlantic species, together with the closely related *P. nanomamillata* Deevey and Brooks, (1980). Comprehensive redescriptions of *Paraconchoecia spinifera* and *Mamilloecia mamillata* new combination are given along with full descriptions of the new genus and species *M. indica*.

3.2 Introduction

In the spring of 1997, during the Northeast monsoon, the RRS *Charles Darwin* undertook the "Scheherezade" cruise to investigate the influence of upwelling on biological processes in the Gulf of Oman. During the cruise a series of horizontal tows was made with the multiple rectangular midwater trawl (RMT1+8) net system (Roe and Shale 1979, Roe et al. 1980) at an oceanic station (*Discovery* 54001, 24° 12'N, 58° 40'E). The water column was sampled in 50 m, 100 m and 200 m depth zones to a depth of 2000 m. Planktonic ostracods were sorted from the RMT 1 samples and analysed for bathymetric distribution and species composition.

In deep water samples (below 1500 m) in the Gulf of Oman there was an abundant population (379 females and 186 males) of a species that is superficially very similar to *Paraconchoecia mamillata* (Müller, 1906) recorded in the Atlantic. Detailed morphometric examination and statistical analysis of specimens from the Gulf and the Atlantic was undertaken to determine if the two forms were conspecific. It was also noted that both these forms showed striking external differences from the type species of *Paraconchoecia*, *P. spinifera* Claus, 1891. Consequently the comparisons were extended to include *P. spinifera* to ascertain whether or not they could be considered to be congeneric. As a result of this study, a new genus is erected to accommodate the species complex related to *Paraconchoecia mamillata*, with the new species from the Gulf of Oman being designated as the type species. In this chapter a detailed redescription of *Paraconchoecia spinifera* is given, followed by detailed descriptions of both the species in *Mamilloecia.*

3.3 Materials and methods

The Atlantic material described herein was derived from:

1) The RRS *Discovery* cruise of 1972, *Discovery* Station 7856 (30º N, 23º W). The net used was the multiple rectangular midwater trawl (RMT1+8) net system (Roe and Shale 1979, Roe et al. 1980) The ostracod species *Paraconchoecia spinifera* was sorted from the RMT1 500 – 600 m depth horizon sample. The Station 7856 was considered to be reasonably close to the two locations from which the species was originally described by Claus (1891).

2) The *Paraconchoecia mamillata* material was collected during the RRS *Discovery* cruise of 1976, *Discovery* Station 9022 (30º12' N, 11º41' W). The net used was the multiple rectangular midwater trawl (RMT1+8) net system (Roe and Shale 1979, Roe et al. 1980). The ostracods were sorted from the RMT1 2000 – 2200 m depth horizon sample and separated into species.

The material from both Station 7856 and Station 9022 was initially fixed on board ship in buffered 5 % formalin and subsequently stored in 80 % industrial methylated ethanol in the collections of the Natural History Museum, London.

The Gulf of Oman zooplankton samples were collected in 1997, during the Northeast monsoon (Herring et al. 1998 and Herring et al. 1999), at Station 54001 from the 1400 – 1600 m depth horizon sample. Total zooplankton samples were initially fixed in 5 % seawater formalin and transferred after 24 h into Steadman's preserving fluid (0.5 % propylene phenoxetol, 4.5 % propylene glycol, 5 % formalin seawater solution) before being stored for later analysis at the Natural History Museum, London. In 2006 the Steadman's preserving fluid was replaced by 80 % industrial methylated ethanol and the planktonic ostracods were picked out and sorted to species.

Measurements of carapace length, breadth and height were taken for both sexes of *Paraconchoecia spinifera,* both sexes of *Mamilloecia indica* and both sexes of *M. mamillata*. A pilot study using scanning electron microscopy (SEM) was undertaken on a specimen of *Mamilloecia indica* to ascertain its potential for halocyprid taxonomy. The material for scanning was cleaned by placing in alcohol and cleaning in glycerol for 12 h, specimens were then dehydrated through graded ethanol before placing in a critical point dryer. The dried specimens were sputter coated with gold before being observed in a Phillips X50 microscope at 15 kV.

A statistical analysis of morphometric characters of the carapace was undertaken to compare *Mamilloecia indica* n. sp. with typical specimens of *Mamilloecia mamillata* n. comb. from the Atlantic. The computer software package SPSS was used for principal component analysis. Principal component analysis was chosen to show differences between individuals rather than groups. Measurements were taken from twenty specimens of each sex of the Oman species and twenty specimens of each sex of the Atlantic species. These measurements were obtained under a stereo-microscope, using a graticule eyepiece to an accuracy of 0.01 mm, and consisted of five external features of the carapace shape: length from rostrum to posterior dorsal corner, rostrum to tubercle, height, posterior dorsal corner to dorsal edge of tubercle and posterior dorsal corner to ventral edge of tubercle (Tables 3.1 A, B, 3.2 A, B).

A female and a male of *Paraconchoecia spinifera*, the type species of the genus *Paraconchoecia,* were dissected. One female and male of *Mamilloecia indica* from the Oman samples and one female and male of *Mamilloecia mamillata* from the Atlantic samples were dissected. Before dissection, each specimen was placed on a cavity slide in lactophenol containing lignin pink, dissected and examined under a stereo-microscope. The limbs were mounted as temporary preparations in lactophenol and examined under an Olympus BH2 compound microscope using differential interference contrast. A standard set of measurements of the limbs and setae (Angel and Blachowiak-Samolyk 2006), and morphological characteristics was recorded. Using a drawing tube, pencil drawings were made of the complete animal and the individual dissected parts. These sketches were scanned, re-drawn using Adobe Illustrator and collated in Adobe Photoshop. Skogsberg's (1920) nomenclature for the structure and setation from the antennae, mandible, maxilla, 5th limb, 6th limb, and caudal furca has been used throughout.

3.4 Results

The SEM study demonstrated the presence of sculpturing on the carapace surface, but the specimen was rather distorted and had collapsed (Figure 3.1). Halocyprids are planktonic and have light, uncalcified carapaces and this result was not entirely unexpected. This explains why there are currently no SEM images of halocyprids in the literature.

3.5 Systematics

Class **OSTRACODA** Latreille, 1802

Subclass **MYODOCOPA** Sars, 1866

Order **HALOCYPRIDA** Dana, 1853

Suborder **HALOCYPRIDINA** Dana, 1853

Family **HALOCYPRIDIDAE** Dana, 1853

Subfamily **CONCHOECIINAE** Claus, 1891

Genus *Paraconchoecia* Claus, 1891

3.6 Diagnosis of *Paraconchoecia,* Claus 1891

Carapace varies in size, shape and form. Right asymmetric gland opens near posterior ventral corner. Left asymmetric gland opens at dorso-posterior corner. There are no lateral glands. Dorso-posterior glands present in male. Frontal organ sexually dimorphic. First antenna spines absent and in male e-seta not widened distally. Masticatory pad of mandible endite forms single triangular plate.

3.7 *Paraconchoecia spinifera* (Claus 1891)

(Figures 3.2 – 3.6)

Paraconchoecia spinifera Claus, 1891:1-81, Brady and Norman, 1896: 695, Müller, 1906: 56, pl. IX, 1-10, 13-14, Müller, 1906: 3 (Siboga), Vavra, 1906: 40, Pl. 2, 29-36, Granata and Caporiacco, 1949: 32, Iles, 1953:270, Leveau, 1965:177, Pl. 5 c-e; 6 a-c, not Leveau, 1967: 67, Deevey, 1968: 30, fig.8 a- e, fig. 9 a – f, Angel, 1981: 560, fig.194-6, Angel, 1993: 208, Fig. 78.
Paraconchoecia spinifera Claus, 1891: 64 Pl.X, Poulsen, 1973: 12-16, fig1 a-i, Chen and Lin, 1995: 76-77, pl. 88, 1-7.

Material
The material was collected from *Discovery* station 7856 (see above). Permanent preparations of dissected specimens used to prepare the illustrations in this paper have been deposited at the Natural History Museum, London: registration number NHMUK 2011.1613 for the female on slides and NHMUK 2011.1614 for the male on slides. The measured 100 males and 100 females are retained in 80% industrial methylated ethanol registration numbers NHMUK 2011.1615 - 1624.

Description The morphological characters of the carapaces and internal structures of both sexes, are listed in Tables 3.5 - 3.12, together with the comparative data for the other species examined: *Mamilloecia indica* and *M. mamillata*.

Female

Carapace (Figures 3.2 A, B, C) Mean length 1.77 ± 0.04 mm (n = 100). Carapace of exemplar specimen (Table 3.5) length 1.82 mm; height 0.90 mm; breadth 0.70 mm. Height:length ratio 49.5 % carapace length (CL), breadth:length ratio 38.5 %CL. Ventral margin of carapace with few striae running parallel to margin. Carapace slightly elongated with sharp edged shoulder vaults, maximum height anterior to mid-length. Ventral margin curving smoothly into posterior margin with asymmetric gland at ventral dorsal corner of right valve. Posterior dorsal corner of right valve furnished with two small spines. Posterior dorsal corner of left valve furnished with blunt process. On left valve asymmetric gland opening on dorsal margin anterior to end of hinge between valves.

Frontal organ (Table 3.5; Figure 3.2 D) Frontal organ stem slender and almost straight, much longer than limb of first antenna. Capitulum bulbous with pointed tip. Distal end of dorsal surface with small spines. Ventral surface covered in small spines. Total length 39.6 %CL longer than first antenna.

First antenna (Table 3.6; Figure 3.2 D) Five-segmented. Limb length 30.0 %CL. Third segment with dorsal seta 22.3 %CL. Fifth segment with five unequal setae; a-seta 15.1 %CL; b-seta 14.8 %CL; c-seta 15.4 %CL; d-seta 15.9 %CL; e-seta 38.2 %CL with long hairs on anterior face.

Second antenna (Table 3.6; Figure 3.2 E) Protopodite 59.8 %CL. First exopodite segment about one third length of protopodite. All swimming setae much shorter than protopodite, all but shortest two setae with long hairs distally. Endopodite (Figure 3.2 F) with short, pointed bare a- and b-setae; c-, d- and e-setae absent; f- and g- setae respectively 26.4 %CL and 44.2 %CL; h-seta 16.2 %CL; i-seta 22.3 %CL; j-seta 22.0 %CL.

Mandible (Table 3.7) (Figures 3.3 A, B, C) Coxale toothed edge of pars incisiva with nine large blunt teeth. Distal tooth list with two large and about ten small pointed teeth. Proximal tooth list slightly narrower with four large teeth and about fifteen small pointed teeth. Outer margin of toothed edge of basal endite with two large dagger-shaped teeth, tip of second rounded, one small pointed tooth and five subserrate teeth. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with one bare dorsal seta and four finely spinose ventral setae. Second segment with two ventral and three dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla (Table 3.7; Figure 3.3 D) Basal segment with four naked and two plumose anterior setae, one lateral and four posterior setae. Distal segment comparatively short and wide with five bare terminal claw setae, posteriormost longest.

Fifth limb (Table 3.8; Figure 3.3 E) Ventrally basale with five setae and one plumose seta, laterally one plumose and two bare setae, dorsally single long seta – remnant of exopodite. First endopodite segment with two ventral setae and one dorsal seta. Second segment with three unequal, curved terminal claw setae; middle claw longest, 6.9 %CL.

Sixth limb (Table 3.8; Figure 3.3 F) Basale with five plumose ventral setae, one plumose seta laterally and one dorsally. First endopodite segment with one ventral seta. Second segment with one seta ventrally and one dorsally. Third segment with three unequal, terminal claw setae; middle claw longest 14.0 %CL.

Caudal furca (Table 3.8; Figure 3.3 G) Eight pairs of claw setae diminishing in size dorsally; longest claw 11.8 %CL.

Male

Carapace (Figures 3.4 A, B, C) Mean length 1.77 ± 0.04 mm (n = 100). Carapace of exemplar specimen (Table 3.9) length 1.76 mm; height 0.86 mm; breadth 0.74 mm. Height:length ratio 48.9 %CL, breadth:length ratio 42.0 %CL. Ventral margin ornamented with few striae. Carapace slightly elongated with sharp edged shoulder vaults; maximum height anterior to mid-length. Ventral margin curving smoothly into posterior margin with left asymmetric gland opening at posterior ventral corner. Posterior dorsal corner of right valve furnished with small spine and blunt process on left valve. Asymmetric gland of left valve opening onto posterior dorsal margin anterior to end of hinge between carapace valves.

Frontal organ (Table 3.9; Figure 3.4 D) Frontal organ stem slender and almost straight, shorter than limb of first antenna. Capitulum, bulbous, bare with pointed tip. Total length 52.0 %CL much longer than first antenna.

First antenna (Table 3.10; Figure 3.4 D) Five-segmented. Limb length 49.7 %CL. Third segment with small dorsal seta 3.4 %CL. Fifth segment with five unequal setae; a-seta 21.0 %CL; b-seta 6.8 %CL; c-seta 42.3 %CL; d-seta 38.9 %CL; e-seta 53.4 %CL with 30 pairs of spinules.

Second antenna (Table 3.10; Figure 3.4 E) Protopodite 51.1 %CL. First exopodite segment about third length of protopodite. All swimming setae much shorter than protopodite, all but shortest two setae bearing long hairs distally. Endopodite with short, pointed, bare a-seta; b-seta pointed with hairs; c-, d- and e-setae present, but all very small; f- and g- setae respectively 38.4 %CL and 44.7 %CL; h-seta 19.6 %CL; i-seta 24.1 %CL; j-seta 20.5 %CL. Right endopodite (Figure 3.5 B) with elongated clasping organ in form of hook with long proximal shank and very long curved end piece 8.2 %CL. Left endopodite (Figure 3.5 A) ‘hook’ much shorter and straight 4.7 %CL.

Mandible, Maxilla and Fifth limb (Table 3.11, 3.12; Figures 3.5 C, D, E, F, 3.6 A) Structure and arrangement of setae on mandible, maxilla and fifth limb as for female.

Sixth limb (Table 3.12; Figure 3.6 B) Basale with five plumose setae ventrally, one laterally, and very short bare dorsal exopodal seta. First endopodite segment with one ventral seta. Second endopodite segment with single seta both ventrally and dorsally. Third segment with three terminal setae. Three subequal, very long setae 35.5 %CL evenly curved ventrally with long hairs distally 35.5 %CL.

Caudal furca (Table 3.12; Figure 3.6 C) Structure and arrangement of furcal claws similar to female. Longest claw 12.2 %CL.

Intromittent organ (Table 3.12; Figure 3.6 C) Male copulatory appendage exceptionally long, 25.9 %CL with eight oblique muscles.

Remarks

The genus *Paraconchoecia* was defined by Claus (1891) and *P. spinifera* was designated type species by Poulsen (1973) when he redefined the genus. *P. spinifera* has been redescribed by Brady and Norman (1896), Müller (1906, 1912), Skogsberg (1920), Deevey (1968) and Poulsen (1973). Müller (1912) recorded *P. spinifera* from the Atlantic, Indian and Pacific oceans and Granata and Caporiacco (1949) reported it in the Mediterranean. Skogsberg (1920) suggested that the diagnosis of the genus by Claus (1891) was insufficient, since the only character defined by him was the masticatory pad of the basal endite of the mandible. Müller (1906) added the character of the long hairs or spines on the e-seta of the first antenna and the absence of lateral glands.

3.8 ***Mamilloecia*** Graves new genus

Conchoecia (part) Müller, 1906a: 60, Pls 16,1-9,35,8, Müller 1906b: 6, Müller, 1912: 70, Granata and Caporiacco, 1949: 30, Iles, 1953: 269, Rudjakov, 1962: 175,fig 1 a – e, Deevey, 1968: 36, fig 12 d – f, Deevey, 1974: 361, Deevey, 1978a: 51, Deevey and Brooks, 1980: 66 fig 11 e – h, 12a, 13b, e – j, Angel, 1981: 559 fig 19 4 - 6
Paraconchoecia (part) Poulsen, 1973: 42 – 43, fig 16 a – j, Chavtur, 1977: 144, 1993 Angel, 1993:186 fig 67, Chen and Lin 1995: 72 fig 831 – 3, Angel et al. 2007: 11 fig 8

Etymology The name is derived from the original specific name of *mamillata*, that refers to the tubercle resembling a mammary gland, and –*oecia* the standard ending for the majority of genera of the subfamily Conchoeciinae.

Type species: *Mamilloecia indica* Graves, by original designation.

3.9 Diagnosis of *Mamilloecia*

Carapace faintly sculptured with parallel lines running at approximately 45º to ventral surface. Right carapace valve with small tubercle at mid-height along posterior margin. Left valve with similar tubercle just below posterior dorsal corner. Asymmetrical carapace glands open at apices of tubercles. Frontal organ sexually dimorphic: female long stem, straight and slender capitulum; male short stem with broad down-turned capitulum clearly sutured with stem. Armature of male first antenna e-seta bearing dense line of fine hairs and widens distally. Second antenna endopodite f- and g-setae widened distally. In both sexes, mandible dorsal seta of first segment long and plumose; longest claw more than three quarters carapace length. Maxilla basal segment bearing six bare anterior setae with four posterior setae, distal segment with two claw setae and three normal setae. Terminal segment of sixth limb of male bearing two long subequal setae with fine hairs distally and one short bare terminal setae.

3.10 ***Mamilloecia indica*** sp.nov.

(Figures 3.7 – 3.11)

Type material

Permanent preparations of the dissected holotype and allotype are deposited in the collections of the Natural History Museum, London registration number NHMUK 2011.1625 for the holotype (female) on slides and NHMUK 2011.1626 for the allotype (male) on slides. The remaining 100 female and 100 male paratypes are retained in 80% industrial methylated ethanol registration numbers NHMUK 2011.1627 - 1636.

Etymology The specific name refers to the type locality of the Indian Ocean.

Description The morphological characters of the carapaces and internal structures are listed in Tables 3.5 – 3.12 together with comparative data for the other species described here.

Female

Carapace (Figures 3.7 A, B, C) Mean length 1.88 ± 0.04 mm (n = 100). Carapace of exemplar specimen (Table 3.5) length 1.84 mm; height 0.68 m; breadth 0.60 mm. Height:length ratio 37.0 %CL, breadth:length ratio 32.6 %CL. In lateral view carapace faintly sculptured with parallel lines running at approximately 45º to ventral surface. Carapace slightly elongated, maximum height just anterior to mid-length. Ventral margin curving smoothly into posterior margin. At mid-height on posterior margin of right carapace tubercular bulge containing asymmetric gland which opens at apex. Posterior dorsal corner of right valve furnished with small pointed spine. Just below posterior dorsal corner of left valve furnished with blunt tubercle with opening of asymmetric gland.

Frontal organ (Table 3.5; Figure 3.7 D) Frontal organ stem slender, almost straight and longer than limb of first antenna. Capitulum with wide rounded end: dorsal surface naked; distal end of ventral surface covered in small spines. Total length 37.5 %CL, much longer than first antenna.

First antenna (Table 3.6; Figure 3.7 D) Five-segmented. Limb length 22.8 %CL. Third segment with dorsal seta 6.0 %CL. Fifth segment with five unequal setae; a-seta 14.1 %CL; b-seta 14.7 %CL; c-seta 14.7 %CL; d-seta15.8 %CL; e-seta 20.9 %CL with long hairs.

Second antenna (Table 3.6; Figure 3.7 E) Protopodite 39.4 %CL. First exopodite segment about half length of protopodite. Most swimming setae similar in length to protopodite, all but shortest two setae with long hairs distally. Endopodite (Figure 3.7 F) with short, pointed a-seta; b-seta pointed and bare; no c-, d- or e-setae; f- and g-setae respectively 16.8 %CL and 20.4 %CL; h-seta 11.7 %CL; i-seta 14.0 %CL; j-seta 12.1 %CL.

Mandible (Table 3.7; Figures 3.8 A, B, C) Coxale toothed edge of pars incisiva with ten large blunt teeth. Distal tooth list with two large and about fifteen small pointed teeth. Proximal tooth list slightly narrower, with two large teeth and about eighteen small pointed teeth. Outer margin of toothed edge of basal endite with two large dagger-shaped teeth, second with rounded tip, one pointed tooth and five subserrate teeth. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with plumose dorsal seta and four finely spinose ventral setae. Second segment with two ventral and three dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla (Table 3.7; Figure 3.8 D) Basal segment with six anterior, one lateral and four posterior setae. Distal segment comparatively short and wide with five bare terminal claw setae, posteriormost longest.

Fifth limb (Table 3.8; Figure 3.8 E) Ventrally basale with one plumose and five spinose setae, laterally one plumose and two bare setae, dorsally single long spinose seta – remnant of exopodite. First endopodite segment with two ventral setae and one dorsal seta, all spinose. Second segment with three unequal, curved terminal claw setae; middle claw longest 4.9 %CL.

Sixth limb (Table 3.8; Figure 3.8 F) Basale with five plumose ventral setae, laterally one plumose seta and one bare seta dorsally. First endopodite segment with one ventral spinose seta. Second segment with one spinose seta ventrally and one dorsally. Third segment with three unequal spinose, terminal claw setae; middle claw longest 11.0 %CL.

Caudal furca (Table 3.8; Figure 3.8 G) Eight pairs of claw setae diminishing in size dorsally; longest claw 11.4 %CL.

Male

Carapace (Figures 3.9 A, B, C) Mean length 1.63 ± 0.04 mm (n = 100). Carapace of exemplar specimen (Table 3.9) length 1.56 mm; height 0.60 mm; breadth 0.64 mm. Height:length ratio 38.5 %CL, breadth:length ratio 41.0 %CL. In lateral view carapace faintly sculptured as in female, maximum height just anterior to mid-length. Ventral margin curving smoothly into posterior margin at similar angle to anterior margin. At mid-height on posterior margin of right valve tubercular bulge containing asymmetric gland. Posterior dorsal corner of right valve furnished with small pointed spine. Posterior dorsal corner of left valve furnished with blunt process with opening of asymmetric gland.

Frontal organ (Table 3.9; Figure 3.9 D) Frontal organ stem straight; shorter than limb of first antenna. Capitulum long, with bulbous distal end. Dorsal surface bare, but proximal ventral surface covered in small spines. Total length 44.2 %CL, much longer than first antenna.

First antenna (Table 3.10; Figure 3.9 D) With five segments. Limb length 38.5 %CL. Third segment with dorsal seta 4.6 %CL. Fifth segment with five unequal setae; a-seta 19.9 %CL; b-seta 33.0 %CL; c-seta 9.9 %CL; d-seta with short fine hairs 29.5 %CL; e-seta 42.3 %CL with long hairs.

Second antenna (Table 3.10; Figure 3.9 E) Protopodite 46.5 %CL. Length of first exopodite segment about one third length of protopodite. All swimming setae shorter than protopodite, all but shortest two setae with long hairs distally. Endopodite with short, pointed, bare a-seta; b-seta pointed with hairs; c-, d-, and e-setae all very short; f- and g- setae respectively 35.9 %CL and 29.2 %CL terminally flattened; h-seta short 7.7 %CL; i-seta 16.3 %CL; j-seta 13.8 %CL. Right endopodite (Figure 3.10 B) with elongated clasping organ in form of hook with long proximal shank and very long curved end piece 10.1 %CL. Left endopodite (Figure 3.10 A) 'hook' much shorter and curved 5.3 %CL.

Mandible, Maxilla and Fifth limb (Table 3.11, 12; Figures 3.10 C, D, E, F, 3.11 A) Structure and arrangement of setae for mandible, maxilla and fifth limb same as in female.

Sixth limb (Table 3.12; Figure 3.11 B) Basale with five plumose setae ventrally, one lateral plumose seta and one bare dorsal exopodal seta. First endopodite segment with single, ventral seta. Second endopodite segment with one seta ventrally and one dorsally. Third segment with three terminal setae, two very long, evenly curved ventrally with long hairs 22.1 %CL and one bare much shorter seta 4.2 %CL.

Caudal furca (Table 3.12; Figure 3.11 C) Structure and arrangement of furcal claws similar to female; longest claw 14.3 %CL.

Intromittent organ (Table 3.12; Figure 3.11 C) Male copulatory appendage exceptionally long, 26.9%CL, with two oblique muscles.

Remarks

The distinctive features of *M. indica* are: tubercle at mid-height on posterior margin with rounded opening; maximum height anterior to mid-length; considerable size difference between female and male (Figures 3.7, 3.9).

3.11 *Mamilloecia mamillata* (Müller, 1906) new combination

(Figures 3.12 – 3.16*)*

Conchoecia mamillata Müller, 1906: 60, Pls 16, 1-9; 35, 8, Müller 1906: 66. (Südpolar), Müller, 1912: 70, Granata and Caporiacco, 1949: 30, Iles, 1953: 269, Rudjakov, 1962: 175, fig.1, a-e, Deevey, 1968 36, fig, 12, d-f, Deevey, 1980 66, figs 11, e-h; 12 a; 13,b, e-j, Angel, 1981: 559, fig. 194-61.

Paraconchoecia mamillata (part) Poulsen, 1973: 42-43, fig. 16, a-j.

Material

The material was collected from *Discovery* station 9022 (see above). Permanent preparations of dissected specimens used to prepare the illustrations in this paper have been deposited in the collections of the Natural History Museum, London: registration number NHMUK 2011 1637 for the female on slides and NHMUK 2011.1638 for the male on slides. The measured 53 females and 40 males are retained in 80% industrial methylated ethanol registration numbers NHMUK 2011.1639 – 1648.

Description A full description is merited here as the species has not been comprehensively illustrated and it is being transferred to the new genus of *Mamilloecia*. The morphological characters of the carapaces and internal structures of both sexes are listed in Tables 3.5 – 3.12, together with comparative data for the other species described here.

Female

Carapace (Figures 3.12 A, B, C) Mean length 1.75 ± 0.03 mm (n = 53). Carapace of exemplar specimen (Table 3.5) length 1.74 mm; height 0.68 m; breadth 0.56 mm. Height:length ratio 39.1 %CL, breadth:length ratio 32.2 %CL. In lateral view carapace faintly sculptured with parallel lines running at approximately 45º to ventral surface. Carapace elongate, maximum height posterior to mid-length. Ventral margin curving smoothly into posterior margin. On posterior margin of right carapace tubercular bulge with asymmetric gland. Posterior dorsal corner of right valve furnished with small pointed spine. Posterior dorsal corner of left valve furnished with blunt process and opening of asymmetric gland.

Frontal organ (Table 3.5; Figure 3.12 D) Frontal organ stem slender, almost straight and longer than limb of first antenna. Capitulum with rounded end and bare dorsal surface, distal end of ventral surface covered in small spinules. Total length 34.9 %CL, much longer than first antenna.

First antenna (Table 3.6; Figure 3.12 D) Five-segmented. Limb length 16.8 %CL. Third segment with dorsal seta 5.8 %CL. Fifth segment with five unequal setae; a-seta 16.7 %CL; b-seta 17.8 %CL; c-seta 17.2 %CL; d-seta 16.7 %CL; e-seta 26.1 %CL with long hairs.

Second antenna (Table 3.6; Figure 3.12 E) Protopodite 32.3 %CL. First exopodite segment about half length of protopodite. Most swimming setae similar in length to protopodite, all but shortest two setae have long hairs distally. Endopodite (Figure 3.12 F) a-seta short, pointed bare; b-seta pointed with hairs; no c-, d- or e-setae; f- and g-setae respectively 20.8 %CL and 23.9 %CL; h-seta 17.0 %CL; i-seta 19.7 %CL; j-seta 18.7 %CL.

Mandible (Table 3.7; Figures 3.13 A, B, C) Coxale toothed edge of pars incisiva with ten large blunt teeth. Distal tooth list with two large and about fifteen small pointed teeth. Proximal tooth list slightly narrower with two large teeth and about eighteen small pointed teeth. Outer margin of toothed edge of basal endite with two large dagger-shaped teeth, second with rounded tip, one pointed tooth and five subserrate teeth. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with plumose dorsal seta and four finely spinose ventral setae. Second segment with two ventral and three dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla (Table 3.7; Figure 3.13 D) Basal segment with six anterior, one lateral and four posterior setae. Distal segment comparatively short and wide with five bare terminal claw setae, posteriormost longest.

Fifth limb (Table 3.8; Figure 3.13 E) Ventrally basale with one plumose and five spinose setae, laterally one plumose and two bare setae, dorsally one long seta. First endopodite segment with two ventral setae and one dorsal seta. Second segment with three unequal, curved terminal claw setae; middle claw longest 5.6 %CL.

Sixth limb (Table 3.8; Figure 3.13 F) Basale with five plumose ventral setae, laterally one plumose seta and one bare seta dorsally. First endopodite segment with one ventral spinose seta. Second segment with one spinose seta ventrally and one dorsally. Third segment with three unequal spinose, terminal claw setae; middle claw longest 10.5 %CL.

Caudal furca (Table 3.8; Figure 3.13 G) Eight pairs of claw setae diminishing in size dorsally; longest claw 9.3 %CL.

Male

Carapace (Figures 3.14 A, B, C) Mean length 1.69 ± 0.04 mm (n = 40). Carapace of exemplar specimen (Table 3.9) length 1.72 mm; height 0.64 mm; breadth 0.62 mm. Height:length ratio 37.2 %CL, breadth:length ratio 36.0 %CL. In lateral view carapace faintly sculptured as in female, maximum height posterior to mid-length. Ventral margin curving smoothly into posterior margin. On posterior margin of right valve tubercular bulge containing asymmetric gland. Posterior dorsal corner of right valve furnished with small pointed spine. Posterior dorsal corner of left valve furnished with blunt process on which asymmetric gland opens.

Frontal organ (Table 3.9; Figure 3.14 D) Frontal organ stem straight and similar in length to limb of first antenna. Capitulum long, with bulbous distal end. Dorsal surface bare, but proximal ventral surface covered in small spinules. Total length 43.3 %CL, much longer than first antenna,

First antenna (Table 3.10; Figure 3.14 D) Five-segmented. Limb length 37.1 %CL. Third segment with dorsal seta 5.7 %CL. Fifth segment with five unequal setae; a-seta 24.1 %CL; b-seta 38.4 %CL; c-seta 11.6 %CL; d-seta with short fine hairs 38.4 %CL; e-seta 40.7 %CL with long hairs.

Second antenna (Table 3.10; Figure 3.14 E) Protopodite 42.2 %CL. First exopodite segment about one third length of protopodite. All swimming setae shorter than protopodite, all but shortest two setae have long hairs distally. Endopodite a-seta short, pointed, bare; b-seta pointed with hairs; c-, d-, and e-setae all very short; f- and g-setae respectively 35.8 %CL and 33.7 %CL; h-seta short 11.6 %CL; i-seta 12.9 %CL; j-seta 12.4 %CL. Right endopodite (Figure 3.15 B) with elongated clasping organ in form of hook with long proximal shank and very long curved end piece 6.8 %CL. Left endopodite (Figure 3.15 A) ‘hook’ much shorter and curved 4.3 %CL.

Mandible, Maxilla and Fifth limb (Tables 3.11, 3.12; Figures 3.15 C, D, E, F, 3.16 A) Structure and arrangement of setae for mandible, maxilla and fifth limb as for female.

Sixth limb (Table 3.12; Figure 3.16 B) Basale with five plumose setae ventrally, one laterally and one bare dorsal exopodal seta. First endopodite segment with one ventral seta. Second endopodite segment with single seta both ventrally and dorsally. Third segment with three terminal setae; two very long, evenly curved ventrally with long hairs 23.0 %CL and one much shorter seta 3.8 %CL.

Caudal furca (Table 3.12; Figure 3.16 C) Structure and arrangement of furcal claws similar to female. Longest claw 14.2 %CL.

Intromittent organ (Table 3.12; Figure 3.16 C) Male copulatory appendage exceptionally long, 29.7 %CL, with two oblique muscles.

Remarks

The carapace shape (Figures 3.7, 3.9, 3.12, 3.14) and measurements (Tables 3.5 – 3.12) of the two species of *Mamilloecia* differ significantly. The maximum height of the carapace in both sexes of *M. mamillata* is posterior to mid-length, whereas in both sexes of *M. indica* it is anterior. The tubercle of both sexes of *M. mamillata* is pointed and positioned about two thirds the way along the posterior margin nearer to the posterior dorsal corner, but in *M. indica* it is rounded and positioned at about mid-height. In *M. mamillata* there is not such a significant difference in length between males and females as in *M. indica*.

The results of the Principal Component Analysis are shown in Tables 3.3 and 3.4.

The principal component analysis for both the Atlantic form and the Oman form of *Mamilloecia* females (Tables 3.3) produced an eigen value of 2.479 that translated to ~ 50 % variation between individuals. For males (Table 3.3) an eigen value of 3.090 translated to ~ 62% variation between individuals. The component matrix (Table 3.4) shows the weightings allocated to each of the variables for the extracted factors. For the females, the results from the component matrix suggests that the best contrast between individuals is obtained by comparing length of rostrum to posterior dorsal corner with length of posterior dorsal corner to below tubercle, i.e. individuals that are longer from rostrum to posterior dorsal corner are shorter from posterior dorsal corner to below tubercle and vice versa. For the males, (Table 3.4) the results suggest the best contrast between individuals is obtained by comparing the length from rostrum to posterior dorsal corner with height, i.e. individuals that are longer from rostrum to posterior dorsal corner show the greatest height and vice versa. The x-axis for the scatterplots for each sex (Figures 3.17, 3.18) is derived from the weighted scores of component 1 and the y-axis is derived from the weighted scores of component 2. Hence, the morphological data on axis 1 correlate with length and axis 2 correlates with shape. Both plots show distinct separation of forms, although there is a little overlap. The principal component analysis of the morphometric characters of the carapace (Figures 3.17, 3.18) provides strong evidence supporting the inference that the two forms are distinct species. The Oman form is here recognised as a new species, *M. indica*. In both sexes the length of the frontal organ and length of the first antenna is significantly longer in *M. indica*, but most setae of the first antenna are longer in *M. mamillata* (Tables 3.6, 3.10*)*. In the male both right and left clasper shank lengths are significantly longer in *M. indica* (Table 3.10).

3.12 Discussion

The carapace and morphologies of the two *Mamilloecia* species examined herein are substantially different from *Paraconchoecia spinifera*. The carapaces of both sexes of *P. spinifera* have high shoulder vaults (Figures 3.2 A, 3.4 A), lack tubercles on the posterior margin of either valve and the position of the right asymmetric gland opens anterior to the back of the hinge between the two valves near the posterior ventral corner. In contrast the carapace of *Mamilloecia indica* (Figure 3.7 A) has low rounded shoulder vaults, has a tubercle at mid-point along the posterior edge of the right valve with the asymmetric gland opening at its apex. The frontal organ of both sexes of *P. spinifera* has a pointed capitulum distally (Figures 3.2 D, 3.4 D), but both sexes of both species of *Mamilloecia* have a rounded capitulum (Figures 3.7 D, 3.9 D, 3.12 D, 3.14 D). The armature of the male e-seta on the first antenna of *P. spinifera* is in the form of paired spines (Figure 3.4 D), whereas the two species of *Mamilloecia* (Figures 3.9 D, 3.14 D) have fine hairs. In the male of *P. spinifera* the g-, h-, i- and j-setae of the second antenna are significantly longer than the male setae of either species of *Mamilloecia* (Table 3.10). In both sexes of *P. spinifera* the pars incisiva on the mandible has nine teeth; the pars incisiva of *Mamilloecia* has ten teeth. On the maxilla of both sexes of *P. spinifera* two of the six anterior setae of the basal segment are plumose, but in *Mamilloecia* all six setae are bare (Tables 3.7, 3.11). The fifth limb of the male *P. spinifera* has six ventral setae on the basale; the male of both species of *Mamilloecia* has five (Figures 3.6 A, 3.11 A, 3.16 A), and on the sixth limb all terminal setae of *P. spinifera* are long and equal, but *Mamilloecia* has one much shorter terminal seta (Figures 3.6 B, 3.11 B, 3.16 B). Collectively this evidence supports the establishment of a new genus, *Mamilloecia,* to include *M. indica* and *M. mamillata,* together with *M. nanomamillata* (Deevey and Brooks 1980) new combination, another closely related species from the subtropical Atlantic, here transferred to the new genus.

After sequencing the CO1 gene of more than 70 species of planktonic ostracods Angel (pers. com.) confirmed that shape and size are a good indication of species differentiation. However, the specimens studied herein could not be used for sequencing studies as they had been fixed and preserved with formaldehyde, which fragments DNA. The principal component analysis, on a total of eighty individuals, showed convincing evidence for the separation of the two species of *Mamilloecia.* Figure 3.17 for the females and Figure18 for the males showed two distinct clusters. This indicated *Mamilloecia indica* is a separate species from *Mamilloecia mamillata*. This method has not previously been used for separating species of ostracod. Schwartz et al. (1985) used principal component analysis for separating *Daphnia pulex* from *Daphnia obtusa,* a freshwater branchiopod crustacean of similar shape and size to an ostracod. The authors measured five morphological characteristics from seven hundred and ninety individuals from twelve North American and two English sites. Scatterplots of these measurements showed two distinct clusters. Based on these clusters the authors assigned the species names *Daphnia pulex* and *Daphnia obtusa.* More recently, Hoskin and Higgie (2008) used principal component analysis to provide evidence of a new species of velvet gecko from Queensland Australia, using seven morphological characteristics on thirty three individuals.

Females similar to *M. mamillata* have been sampled at much greater depths (over 3000 m) at *Discovery* Station 9131 (20º 7'N 21º 32'W) are also larger and different in shape, thus suggesting they represent yet another cryptic species in the Atlantic.

3.13 Tables and Figures

Table 3.1 A. Atlantic female *Mamilloecia* measurements (mm) for principal component analysis.

Species number	Rostrum to posterior dorsal corner	Height	Rostrum to tubercle	Posterior dorsal corner to above tubercle	Posterior dorsal corner to below tubercle
1	1.76	0.66	1.74	0.20	0.32
2	1.66	0.64	1.70	0.22	0.30
3	1.68	0.60	1.70	0.22	0.30
4	1.76	0.64	1.74	0.20	0.32
5	1.68	0.64	1.70	0.24	0.30
6	1.78	0.66	1.78	0.24	0.32
7	1.74	0.68	1.78	0.28	0.34
8	1.70	0.64	1.72	0.22	0.30
9	1.74	0.64	1.76	0.22	0.32
10	1.76	0.66	1.76	0.18	0.30
11	1.72	0.64	1.74	0.18	0.34
12	1.70	0.60	1.74	0.18	0.30
13	1.70	0.64	1.74	0.22	0.32
14	1.76	0.64	1.78	0.18	0.26
15	1.72	0.66	1.74	0.20	0.30
16	1.74	0.62	1.76	0.22	0.30
17	1.64	0.58	1.68	0.20	0.30
18	1.68	0.62	1.68	0.18	0.32
19	1.78	0.68	1.78	0.18	0.30
20	1.70	0.66	1.70	0.24	0.34

Table 3.1 B. Oman female *Mamilloecia* measurements (mm) for principal component analysis.

Species number	Rostrum to posterior dorsal corner	Height	Rostrum to tubercle	Posterior dorsal corner to above tubercle	Posterior dorsal corner to below tubercle
1	1.86	0.64	1.94	0.14	0.26
2	1.84	0.70	1.80	0.18	0.30
3	1.82	0.72	1.88	0.16	0.26
4	1.88	0.66	1.88	0.22	0.34
5	1.86	0.62	1.88	0.18	0.32
6	1.80	0.68	1.82	0.24	0.30
7	1.86	0.66	1.88	0.18	0.34
8	1.84	0.66	1.86	0.16	0.32
9	1.88	0.66	1.90	0.20	0.30
10	1.86	0.66	1.88	0.14	0.28
11	1.86	0.68	1.90	0.22	0.34
12	1.84	0.64	1.88	0.16	0.28
13	1.88	0.64	1.92	0.12	0.24
14	1.92	0.64	1.96	0.20	0.34
15	1.82	0.62	1.84	0.20	0.30
16	1.84	0.66	1.86	0.18	0.28
17	1.82	0.60	1.88	0.18	0.30
18	1.80	0.60	1.84	0.18	0.34
19	1.80	0.66	1.82	0.16	0.34
20	1.74	0.64	1.78	0.18	0.30

Table 3.2 A. Atlantic male *Mamilloecia* measurements (mm) for principal component analysis.

Species number	Rostrum to posterior dorsal corner	Height	Rostrum to tubercle	Posterior dorsal corner to above tubercle	Posterior dorsal corner to below tubercle
1	1.60	0.60	1.62	0.18	0.28
2	1.56	0.56	1.60	0.18	0.26
3	1.64	0.56	1.64	0.18	0.26
4	1.58	0.54	1.60	0.16	0.28
5	1.60	0.64	1.64	0.16	0.26
6	1.64	0.56	1.62	0.18	0.30
7	1.62	0.64	1.66	0.14	0.28
8	1.58	0.66	1.58	0.16	0.26
9	1.58	0.56	1.60	0.16	0.26
10	1.56	0.56	1.58	0.16	0.24
11	1.58	0.54	1.62	0.18	0.28
12	1.66	0.54	1.68	0.14	0.26
13	1.58	0.60	1.62	0.14	0.28
14	1.60	0.54	1.62	0.16	0.30
15	1.60	0.60	1.64	0.20	0.30
16	1.66	0.58	1.68	0.18	0.28
17	1.64	0.64	1.68	0.18	0.26
18	1.64	0.56	1.66	0.16	0.26
19	1.58	0.56	1.62	0.14	0.24
20	1.64	0.58	1.68	0.18	0.28

Table 3.2 B. Oman male *Mamilloecia* measurements (mm) for principal component analysis.

Species number	Rostrum to posterior dorsal corner	Height	Rostrum to tubercle	Posterior dorsal corner to above tubercle	Posterior dorsal corner to below tubercle
1	1.60	0.60	1.62	0.18	0.28
2	1.56	0.56	1.60	0.18	0.26
3	1.64	0.56	1.64	0.18	0.26
4	1.58	0.54	1.60	0.16	0.28
5	1.60	0.64	1.64	0.16	0.26
6	1.64	0.56	1.62	0.18	0.30
7	1.62	0.64	1.66	0.14	0.28
8	1.58	0.66	1.58	0.16	0.26
9	1.58	0.56	1.60	0.16	0.26
10	1.56	0.56	1.58	0.16	0.24
11	1.58	0.54	1.62	0.18	0.28
12	1.66	0.54	1.68	0.14	0.26
13	1.58	0.60	1.62	0.14	0.28
14	1.60	0.54	1.62	0.16	0.30
15	1.60	0.60	1.64	0.20	0.30
16	1.66	0.58	1.68	0.18	0.28
17	1.64	0.64	1.68	0.18	0.26
18	1.64	0.56	1.66	0.16	0.26
19	1.58	0.56	1.62	0.14	0.24
20	1.64	0.58	1.68	0.18	0.28

Table 3.3. Total variance of females and males.

Females

Component	Initial eigen values			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.479	49.577	49.577	2.479	49.577	49.577
2	1.296	25.912	75.489	1.296	25.912	75.489
3	0.83	16.595	92.085			
4	0.363	7.26	99.345			
5	0.033	0.655	100.000			

Males

Component	Initial eigen values			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.090	61.790	61.79	3.090	61.790	61.790
2	0.948	18.960	80.75	0.948	18.960	80.750
3	0.653	13.062	93.812			
4	0.251	5.027	98.839			
5	0.058	1.161	100.000			

1 = Rostrum to posterior dorsal corner
2 = Height
3 = Rostrum to tubercle
4 = Posterior dorsal corner to above tubercle
5 = Posterior dorsal corner to below tubercle

Table 3.4. Component matrix of females and males.

Females

	Component	
	1	2
Rostrum to posterior dorsal corner	0.920	0.299
Height	0.369	0.586
Rostrum to tubercle	0.926	0.193
Posterior dorsal corner to above tubercle	-0.694	0.557
Posterior dorsal corner to below tubercle	-0.396	0.718

Males

	Component	
	1	2
Rostrum to posterior dorsal corner	0.927	-0.042
Height	0.297	0.945
Rostrum to tubercle	0.883	0.025
Posterior dorsal corner to above tubercle	0.866	-0.147
Posterior dorsal corner to below tubercle	0.783	-0.174

Table 3.5. Female *Paraconchoecia* and *Mamilloecia* species comparisons (n = 1, %CL = Carapace Length, PDC = posterior dorsal corner, PVC = posterior ventral corner).

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Carapace			
length	1.82 mm	1.84 mm	1.74 mm
height	0.90 mm	0.68 mm	0.68 mm
breadth	0 70 mm	0.60 mm	0.56 mm
height/length %	49.5%	37.0%	39.1%
breadth/length %	38.5%	32.6%	32.2%
PDC, left tip to posterior hinge (%CL)	5.2%	5.7%	5.2%
PDC, right tip to posterior hinge (%CL)	6.0%	5.2%	4.3%
rostrum, left tip to anterior hinge (%CL)	11.8%	11.7%	12.1%
rostrum, right tip to anterior hinge (%CL)	11.8%	10.9%	11.8%
incisure, left rostrum tip to inner edge (%CL)	13.7%	10.1%	12.4%
incisure, right rostrum tip to inner edge (%CL)	13.2%	11.1%	11.5%
opening of left gland	at PDC	at PDC	at PDC
opening of right gland	close to PVC	at tubercle	at tubercle
Frontal organ			
capitulum length (%CL)	12.4%	13.2%	13.5%
stem length (%CL)	27.2%	24.3%	21.4%
total length	39.6%	37.5%	34.9%
stem length relative to antenna 1	longer	significantly longer	significantly longer

Table 3.6. Female *Paraconchoecia and Mamilloecia* species comparisons (n = 1, %CL = Carapace Length).

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Antenna 1			
length segment 1 (%CL)	9.9%	7.1%	4.3%
length segment 2 (%CL)	7.3%	7.1%	3.0%
length segment 3 (%CL)	9.6%	6.0%	6.6%
length segment 4 (%CL)	1.6%	1.5%	1.9%
length segment 5 (%CL)	1.4%	1.2%	1.0%
total length (%CL)	30.0%	22.8%	16.8%
a-seta (%CL)	15.1%	14.1%	16.7%
b-seta (%CL)	14.8%	14.7%	17.8%
c-seta (%CL)	15.4%	14.7%	17.2%
d-seta (%CL)	15.9%	15.8%	16.7%
e-seta (%CL)	38.2%	20.9%	26.1%
dorsal seta (%CL)	22.3%	6.0%	5.8%
Antenna 2			
protopodite (%CL)	59.8%	39.4%	32.3%
exopodite 1 (%CL)	17.9%	16.0%	13.8%
exopodite 2 - 9 (% exopodite 1)	46.2%	44.1%	54.2%
longest swimming seta (%CL)	27.5%	29.9%	31.0%
mid-length swimming seta (%CL)	15.7%	14.3%	21.0%
shortest swimming seta (%CL)	6.0%	3.8%	7.9%
endopodite segment 1 (%CL)	8.8%	7.3%	7.6%
a-seta (%CL)	2.3%	2.2%	2.6%
b-seta (%CL)	3.6%	4.3%	5.0%
endopodite segment 2 (%CL)	2.9%	2.9%	2.9%
f-seta (%CL)	26.4%	16.8%	20.8%
g-seta (%CL)	44.2%	20.4%	23.9%
h-seta (%CL)	16.2%	11.7%	17.0%
i-seta (%CL)	22.3%	14.0%	19.7%
j-seta (%CL)	22.0%	12.1%	18.7%

Table 3.7. Female *Paraconchoecia and Mamilloecia* species comparisons (n = 1, %CL = Carapace Length).

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Mandible			
basale			
endopodite segment 1 dorsal setae	1 bare	1 long plumose	I long plumose
endopodite segment 1 ventral setae	4	4	4
endopodite segment 2 dorsal setae	3	3	3
endopodite segment 2 ventral setae	2	2	2
endopodite segment 3 terminal setae	7	7	7
endopodite segment 3 longest claw (%CL)	17.3%	15.2%	14.9%
endopodite segment 3 longest claw (% limb)	64.9%	77.8%	76.5%
teeth on basal endite	2 + 1 + 5	2 + 1 + 5	2 + 1 + 5
pars incisiva	9	4 + 6	4 + 6
distal tooth list	2 + 10	2 + 15	2 + 15
proximal list	4 + 15	2 + 18	2 + 18
setae laterally on endite	2 + 2	4	4
exopodite	1 plumose	1 plumose	1 plumose
Maxilla			
basal segment anterior setae	4 + 2 plumose	6	6
basal segment lateral setae	1	1	1
basal segment posterior setae	3	4	4
terminal spines	0	0	0
distal segment claw setae	2	2	2
distal segment normal setae	3	3	3

Table 3.8. Female *Paraconchoecia and Mamilloecia* species comparisons (n = 1, %CL = Carapace Length).

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Fifth limb			
basale ventral setae	3 + 2 + 1 plumose	3 + 2 + 1 plumose	3 + 2 + 1 plumose
basale lateral setae	2	2 + 1 plumose	2 + 1 plumose
basale dorsal setae	1 long	1 long	1 long
endopodite segment 1 ventral setae	2	2	2
endopodite segment 1 dorsal setae	1	1	1
height/length %	24.1%	26.1%	35.7%
longest terminal seta (%CL)	6.9%	4.9%	5.6%
longest seta/length segment 2	384.0%	400.0%	411.1%
longest seta/length limb	43.1%	50.7%	41.6%
Sixth limb			
basale ventral setae	2 + 2 + 1 all plumose	2 + 2 + 1 all plumose	2 + 2 + 1 all plumose
basale lateral setae	1	1 plumose	1 plumose
basale dorsal setae	1	1	1
endopodite segment 1 ventral setae	1	1	1
endopodite segment 1 dorsal setae	0	0	0
endopodite segment 2 ventral setae	1	1	1
endopodite segment 2 dorsal setae	1	1	1
segment 2 height/length %			
longest seta (%CL)	14.0%	11.0%	10.5%
longest seta % segment 2	122.9%	168.8%	158.7%
longest seta % limb	40.5%	48.2%	46.8%
Caudal furca			
paired claws			
longest claw (%CL)	11.8%	11.4%	9.3%

Table 3.9. Male *Paraconchoecia* and *Mamilloecia* species comparisons (n = 1, %CL = Carapace Length, PDC = posterior dorsal corner, PVC = posterior ventral corner).

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Carapace			
length	1.76 mm	1.56 mm	1.72 mm
height	0.86 mm	0.60 mm	0.64 mm
breadth	0.74 mm	0.64 mm	0.62 mm
height/length %	48.9%	38.5%	37.2%
breadth/length %	42.0%	41.0%	36.0%
PDC, left tip to posterior hinge (%CL)	3.1%	5.1%	4.9%
PDC, right tip to posterior hinge (%CL)	2.7%	4.2%	3.8%
rostrum, left tip to anterior hinge (%CL)	23.9%	14.1%	12.5%
rostrum, right tip to anterior hinge (%CL)	23.6%	13.5%	12.2%
incisure, left rostrum tip to inner edge (%CL)	14.2%	15.1%	16.0%
incisure, right rostrum tip to inner edge (%CL)	14.5%	13.8%	14.2%
opening of left gland	at PDC	at PDC	at PDC
opening of right gland	close to PVC	at tubercle	at tubercle
Frontal organ			
capitulum length (%CL)	18.2%	18.9%	16.6%
stem length (%CL)	33.8%	25.3%	26.7%
total length (%CL)	52.0%	44.2%	43.3%
stem length relative to antenna 1	shorter	shorter	shorter

Table 3.10. Male *Paraconchoecia* and *Mamilloecia* species comparisons (n = 1, %CL = Carapace Length).

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Antenna 1			
length segment 1 (%CL)	18.2%	9.8%	7.3%
length segment 2 (%CL)	10.5%	9.5%	7.7%
length segment 3 (%CL)	15.9%	9.1%	13.8%
length segment 4 (%CL)	2.6%	5.6%	5.4%
length segment 5 (%CL)	2.6%	4.5%	2.9%
total length (%CL)	49.7%	38.5%	37.1%
a-seta (%CL)	21.0%	19.9%	24.1%
b-seta (%CL)	42.3%	33.0%	38.4%
c-seta (%CL)	6.8%	9.9%	11.6%
d-seta (%CL)	38.9%	29.5%	38.4%
e-seta (%CL)	53.4%	42.3%	40.7%
e-seta armature	30 pairs of spines	double row of fine hairs	double row of fine hairs
dorsal seta (%CL)	3.4%	4.6%	5.7%
Antenna 2			
protopodite (%CL)	51.1%	46.5%	42.2%
exopodite 1 (%CL)	18.2%	16.0%	16.9%
exopodite 2 - 9 (% exopodite 1)	50.0%	56.0%	44.8%
longest swimming seta (%CL)	36.4%	38.5%	28.5%
mid-length swimming seta (%CL)	16.8%	22.1%	9.0%
shortest swimming seta (%CL)	2.7%	9.9%	2.5%
endopodite segment 1 (%CL)	9.4%	6.1%	7.6%
a-seta (%CL)	3.0%	3.8%	3.6%
b-seta (%CL)	4.1%	5.4%	5.4%
endopodite segment 2 (%CL)	4.0%	4.2%	3.2%
f-seta (%CL)	38.4%	35.9%	35.8%
g-seta (%CL)	44.7%	29.2%	33.7%
right clasper shank length (%CL)	8.2%	10.1%	6.8%
left clasper shank length (%CL)	4.7%	5.3%	4.3%
h-seta (%CL)	19.6%	7.7%	11.6%
i-seta (%CL)	24.1%	16.3%	12.9%
j-seta (%CL)	20.5%	13.8%	12.4%

Table 3.11. Male *Paraconchoecia* and *Mamilloecia* species comparisons (n = 1, %CL = Carapace Length).

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Mandible			
basale			
endopodite segment 1 dorsal setae	1 bare	1 long plumose	1 plumose
endopodite segment 1 ventral setae	4	4	4
endopodite segment 2 dorsal setae	3	3	3
endopodite segment 2 ventral setae	2	2	2
endopodite segment 3 terminal setae	7	7	7
endopodite segment 3 longest claw (%CL)	17.3%	16.3%	16.9%
endopodite segment 3 longest claw (% limb)	62.2%	78.5%	85.3%
teeth on basal endite	2 + 1 + 5	2 + 1 + 5	2 + 1 + 5
pars incisiva	9	4 + 6	4 + 6
distal tooth list	2 + 10	2 + 15	2 + 17
proximal list	4 + 12	2 + 18	2 + 16
setae laterally on endite	2 + 2	4	4
exopodite	1 plumose	1 plumose	1 plumose
Maxilla			
basal segment anterior setae	4 + 2 plumose	6	6
basal segment lateral setae	1	1	1
basal segment posterior setae	3	4	4
terminal spines	0	0	0
distal segment claw setae	2	2	2
distal segment normal setae	3	3	3

Table 3.12. Male *Paraconchoecia* and *Mamilloecia* species comparisons (n = 1, %CL = Carapace Length).

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Fifth limb			
basale ventral setae	3 + 3 + 1 plumose	3 + 2 + 1 plumose	3 + 2 + 1 plumose
basale lateral setae	2 + 1 plumose	2 + 1 plumose	2 + 1 plumose
basale dorsal setae	1 long	1 long	1 long
endopodite segment 1 ventral setae	2	2	2
endopodite segment 1 dorsal setae	1	1	1
height/length %	31.0%	32.5%	28.6%
longest terminal seta (%CL)	8.4%	6.3%	5.7%
longest seta/length segment 2	491.7%	520.0%	780.0%
longest seta/limb length	50.0%	48.1%	49.4%
Sixth limb			
basale ventral setae	2 + 2 + 1 all plumose	2 + 1 + 2 all plumose	2 + 2 + 1 all plumose
basale lateral setae	1 plumose	1 plumose	1 plumose
basale dorsal setae	1	1	1
endopodite segment 1 ventral setae	1	1	1
endopodite segment 1 dorsal setae	0	0	0
endopodite segment 2 ventral setae	1	1	1
endopodite segment 2 dorsal setae	1	1	1
segment 2 height/length%	22.9%	30.0%	27.1%
longest seta (%CL)	35.5%	22.1%	23.0%
shortest seta (%CL)	all subequal	4.2%	3.8%
longest seta % segment 2	260.4%	345.0%	329.2%
longest seta % limb	96.9%	94.5%	103.9%
Caudal furca			
longest claw (%CL)	12.2%	14.3%	14.2%
Intromittent organ			
length (%CL)	25.9%	26.9%	29.7%

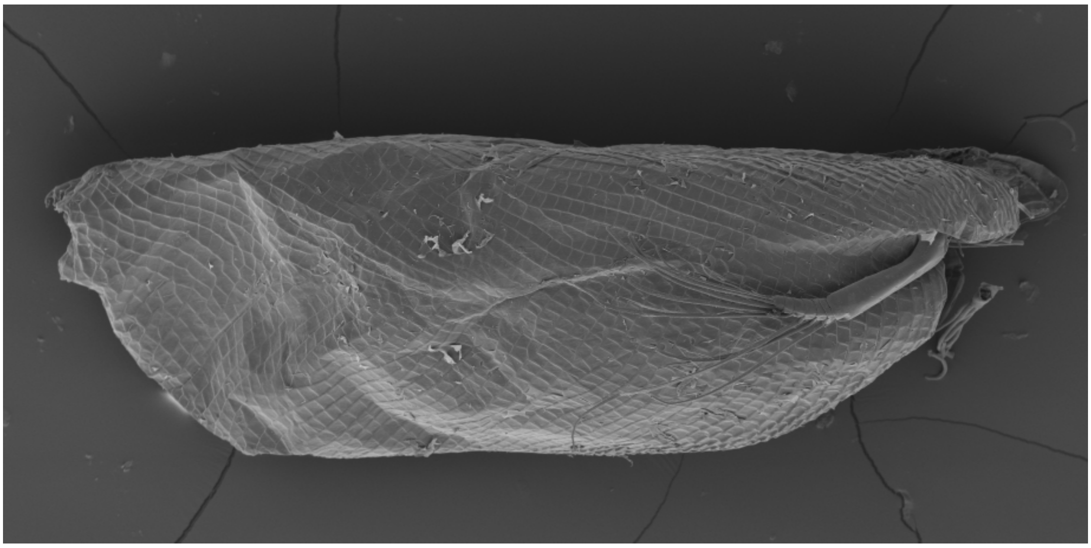


Figure 3.1. SEM image of female *Mamilloecia indica*.

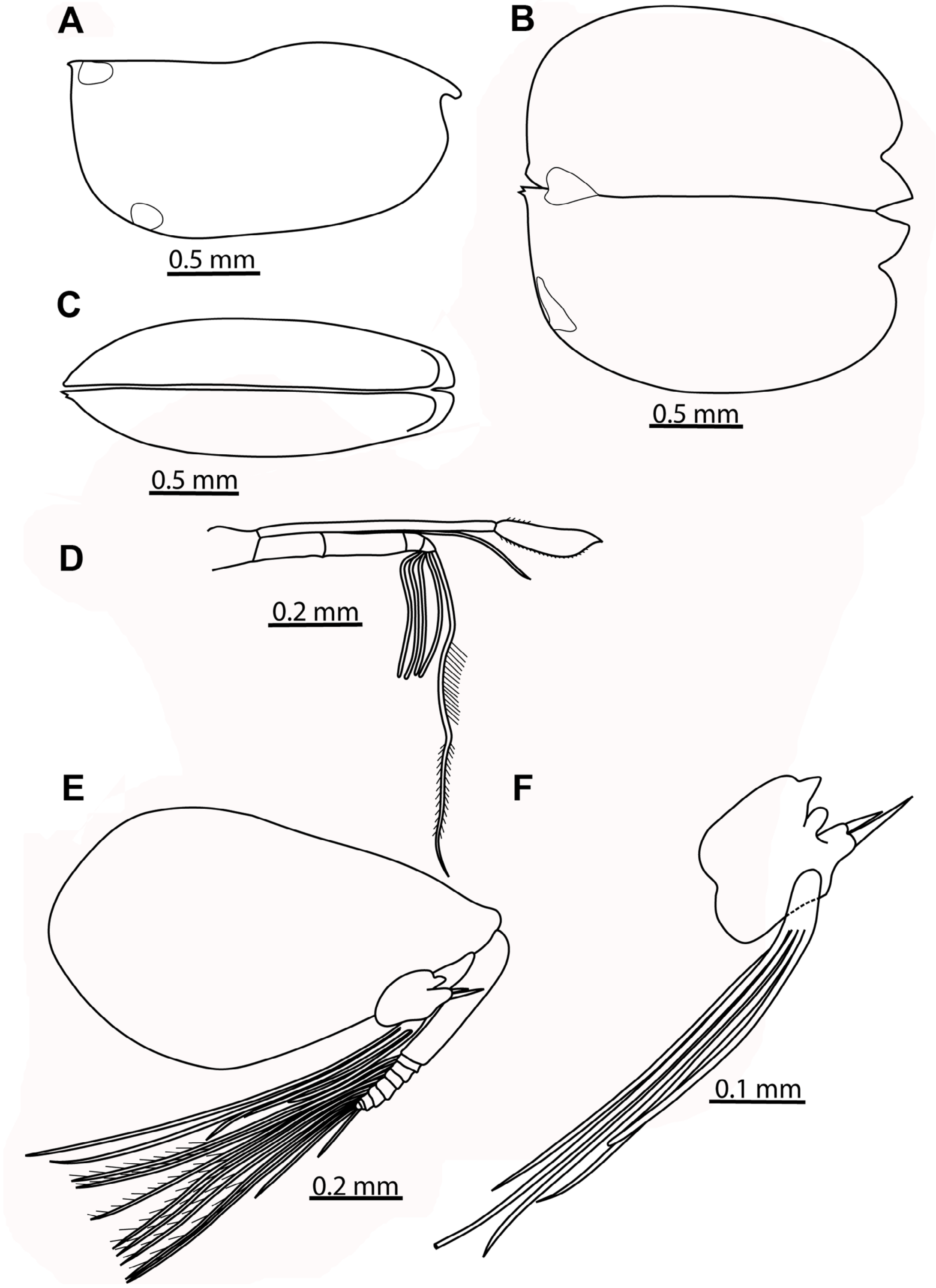


Figure 3.2. *Paraconchoecia spinifera* female (A) lateral view, (B) carapace dissected and viewed dorsally, (C) ventral view, (D) first antenna and frontal organ, (E) second antenna, (F) endopodite.

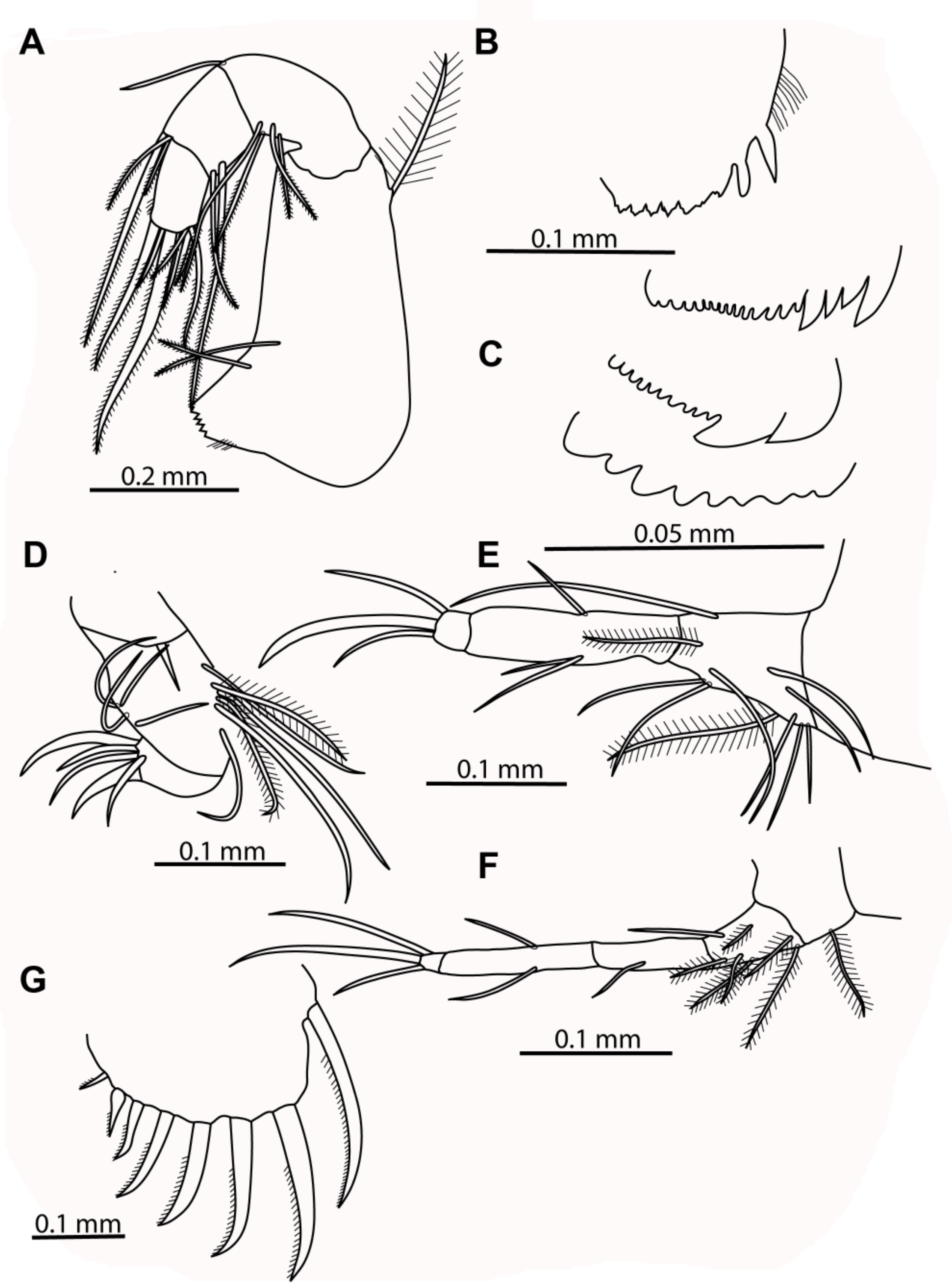


Figure 3.3. *Paraconchoecia spinifera* female (A) mandible, (B) basal endite of mandible, (C) Tooth lists, (D) maxilla, (E) fifth limb, (F) sixth limb, (G) caudal furca.

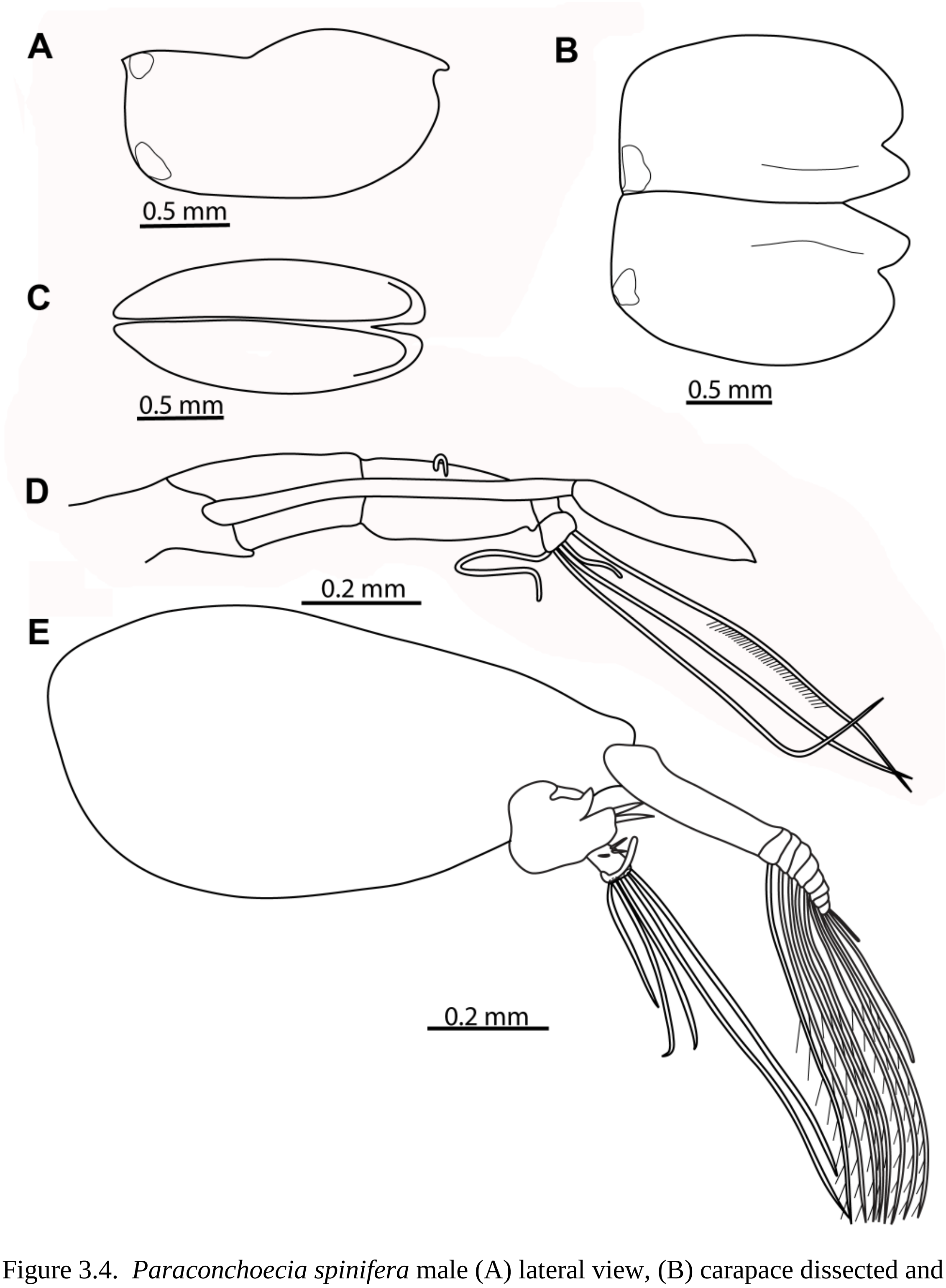


Figure 3.4. *Paraconchoecia spinifera* male (A) lateral view, (B) carapace dissected and viewed dorsally, (C) ventral view, (D) first antenna and frontal organ, (E) second antenna.

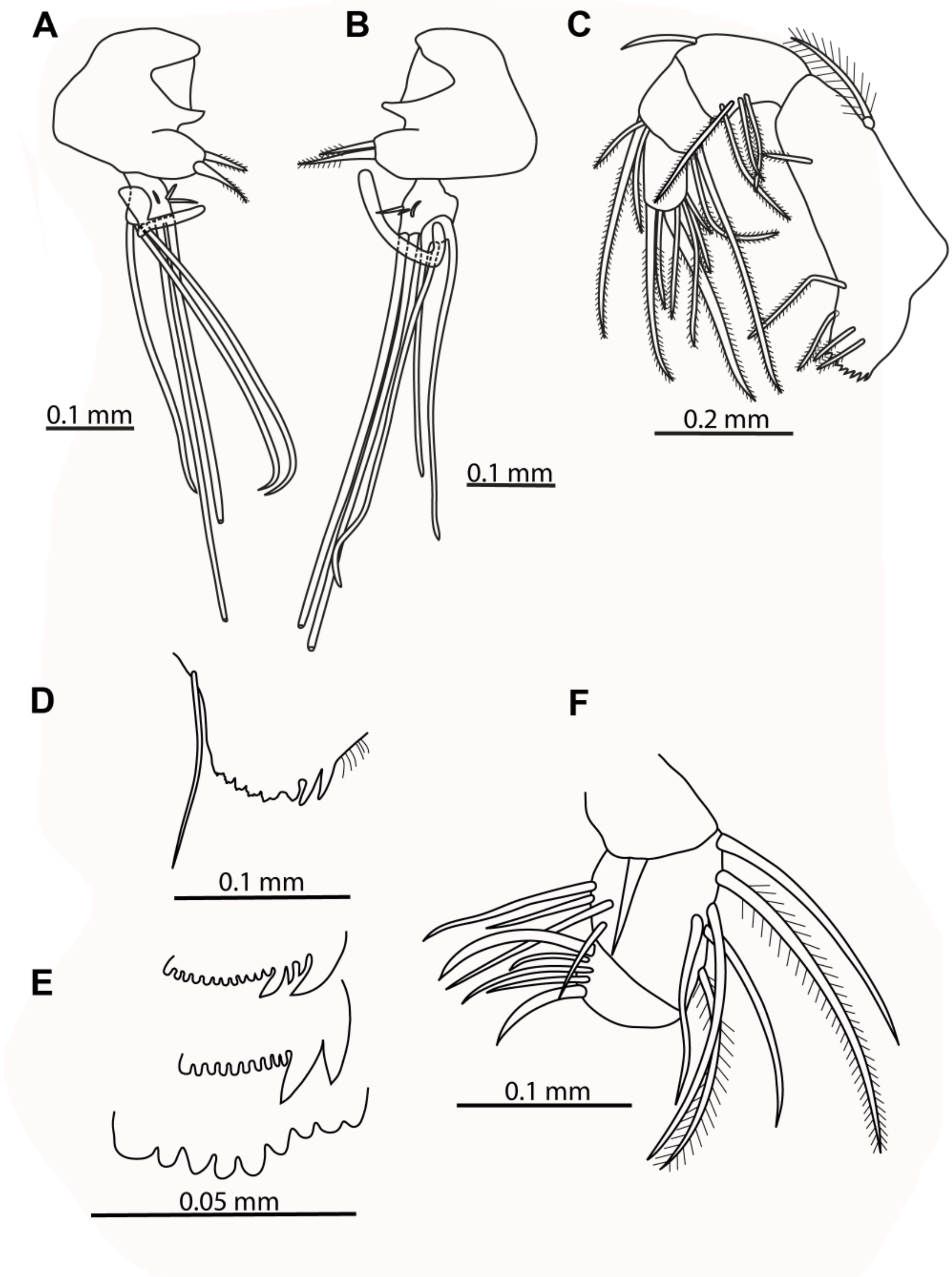


Figure 3.5. *Paraconchoecia spinifera* male (A) left endopodite of second antenna, (B) right endopodite of second antenna, (C) mandible, (D) basal endite of mandible, (E) tooth lists, (F) maxilla.

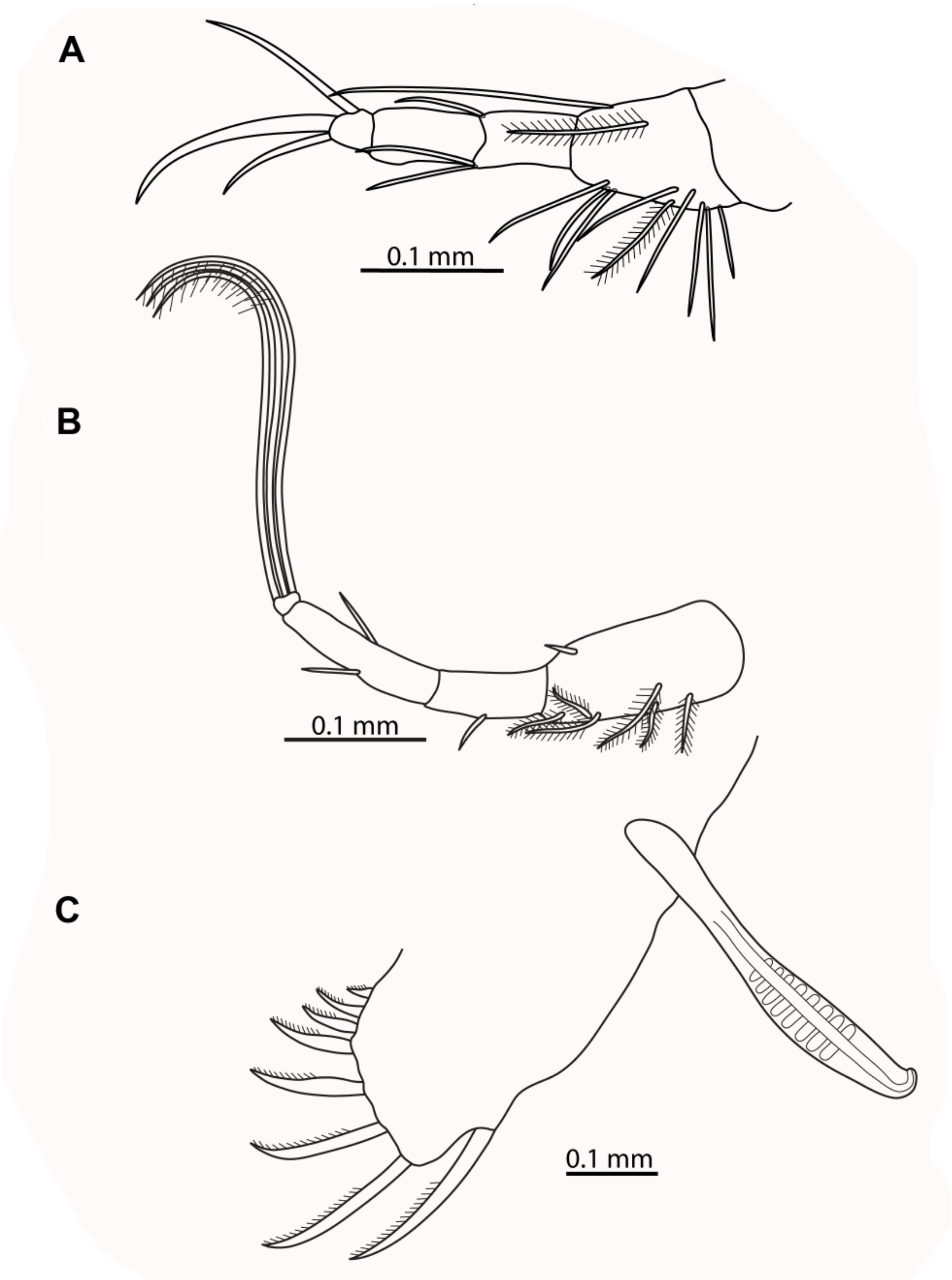


Figure 3.6. *Paraconchoecia spinifera* male (A) fifth limb, (B) sixth limb, (C) caudal furca and intromittent organ.

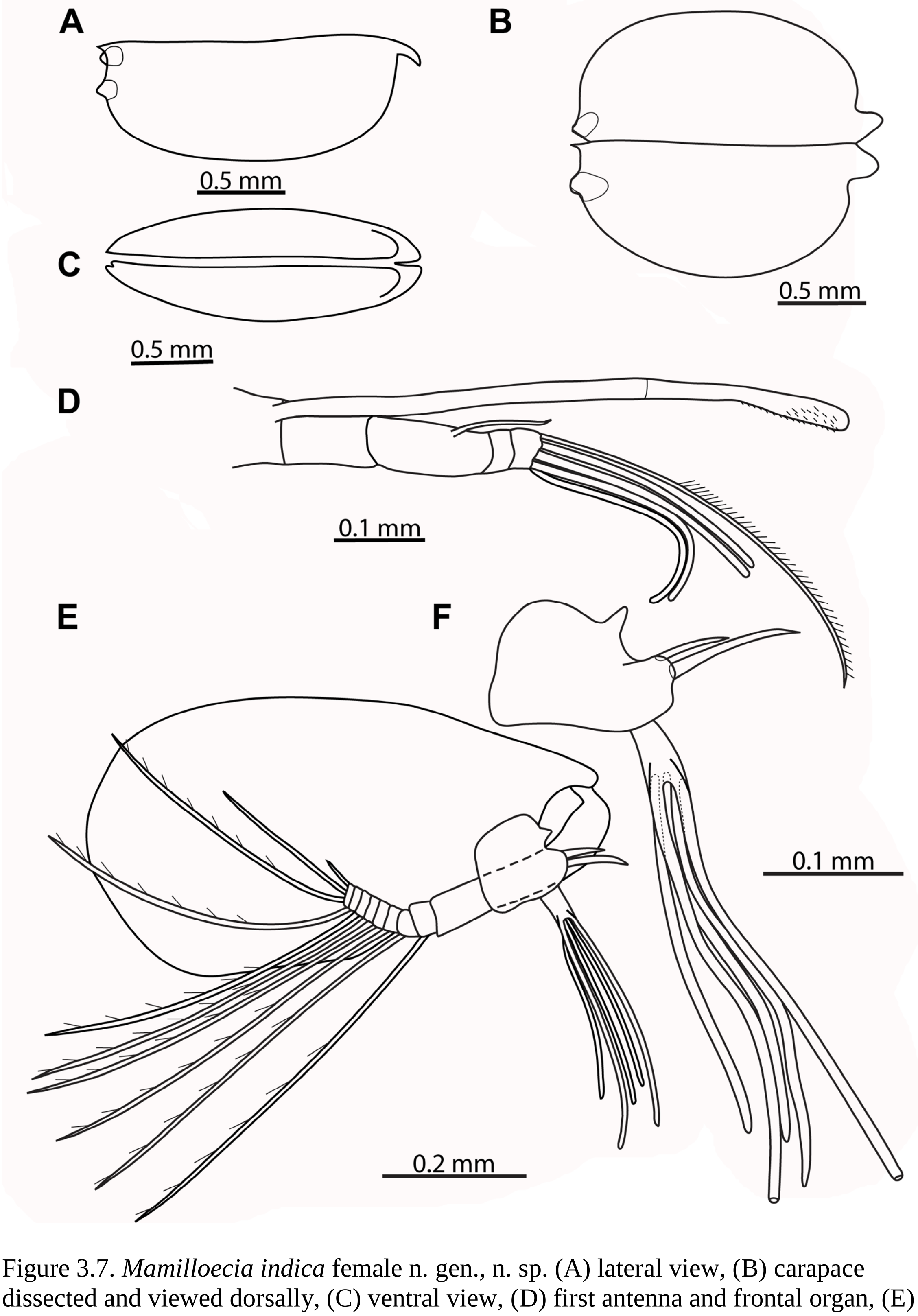


Figure 3.7. *Mamilloecia indica* female n. gen., n. sp. (A) lateral view, (B) carapace dissected and viewed dorsally, (C) ventral view, (D) first antenna and frontal organ, (E) second antenna, (F) endopodite.

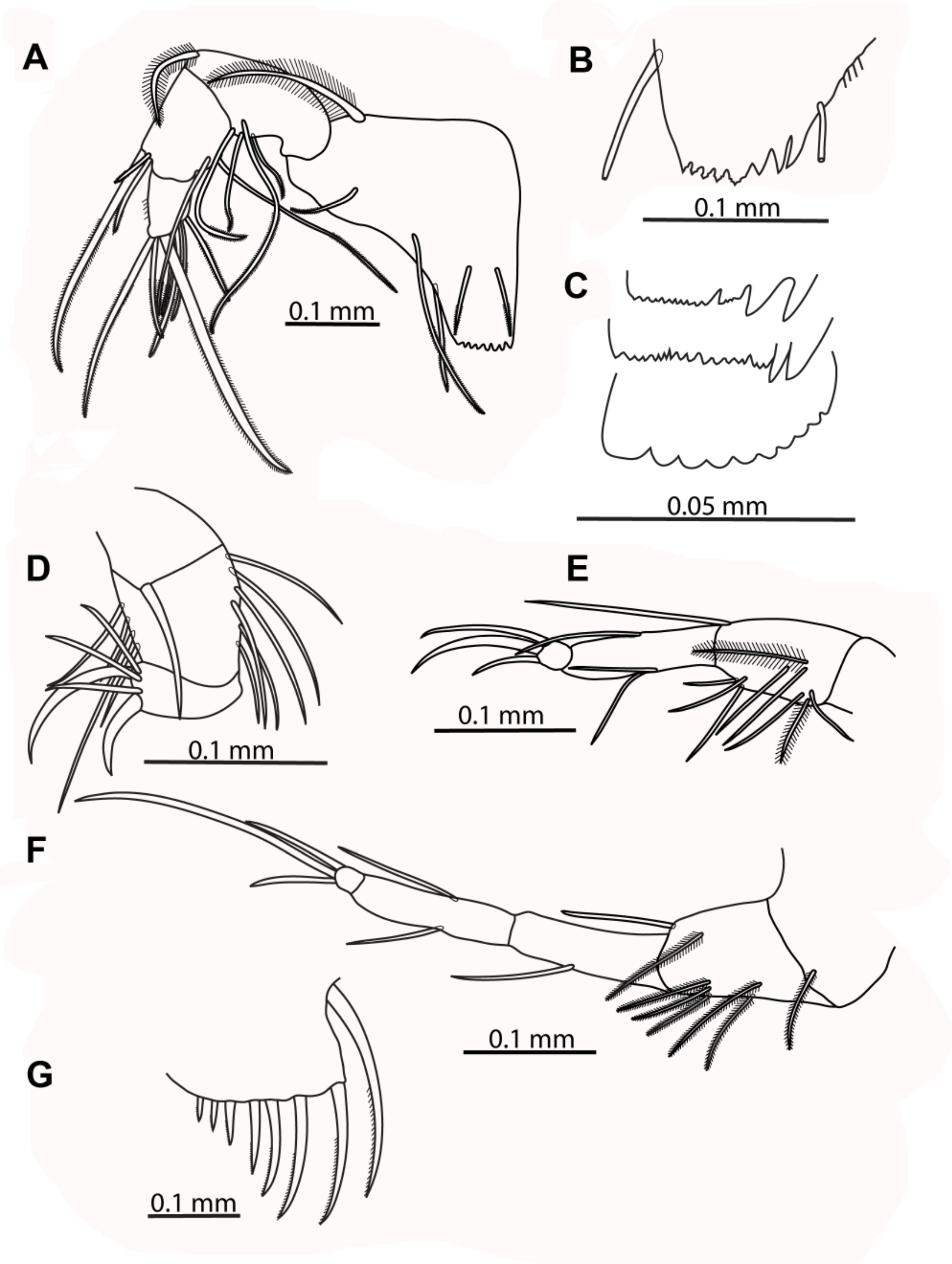


Figure 3.8. *Mamilloecia indica* female n. gen., n. sp. (A) mandible, (B) basal endite of mandible, (C) Tooth lists, (D) maxilla, (E) fifth limb, (F) sixth limb, (G) caudal furca.

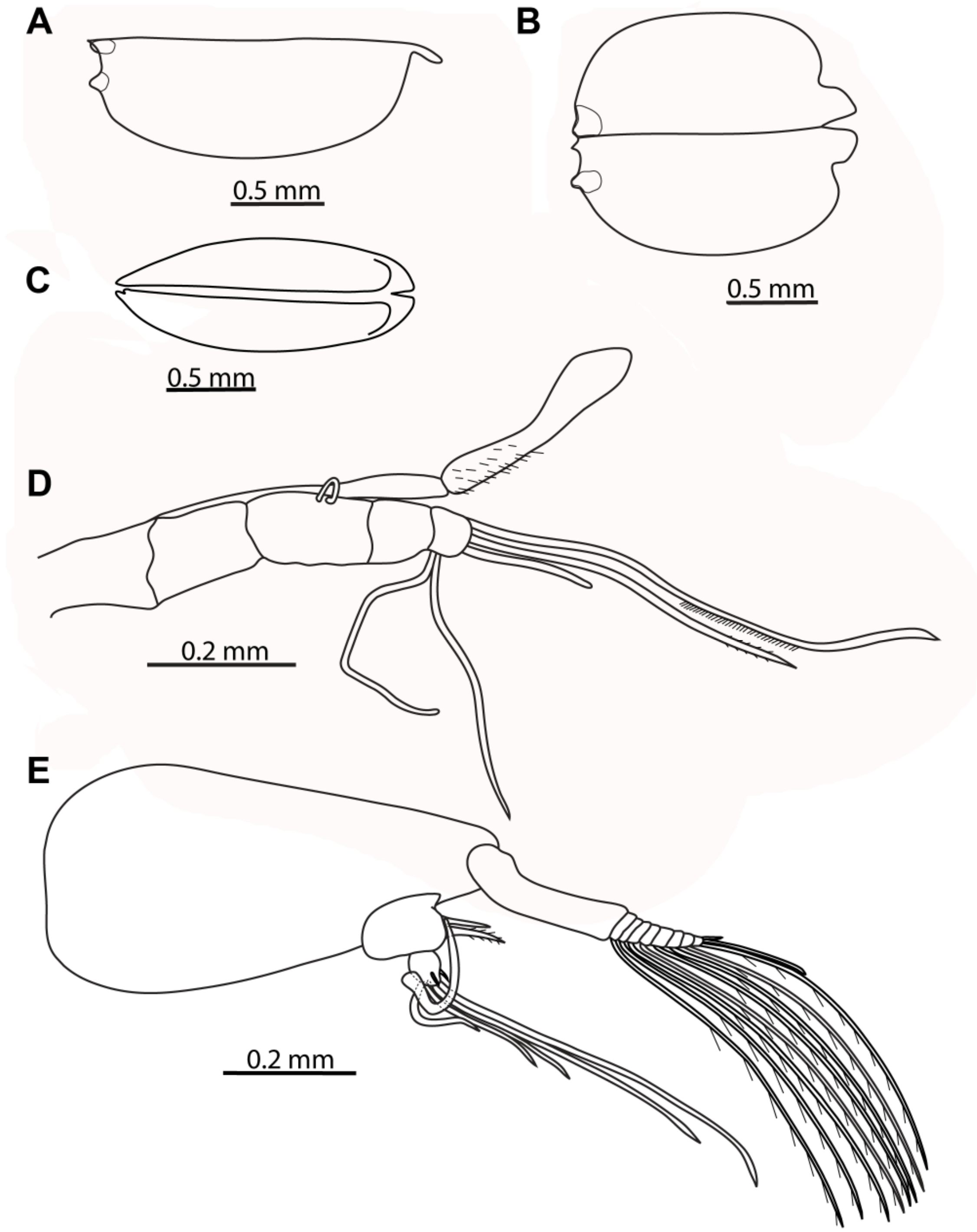


Figure 3.9. *Mamilloecia indica* male n. gen., n. sp. (A) lateral view, (B) carapace dissected and viewed dorsally, (C) ventral view, (D) first antenna and frontal organ, (E) second antenna.

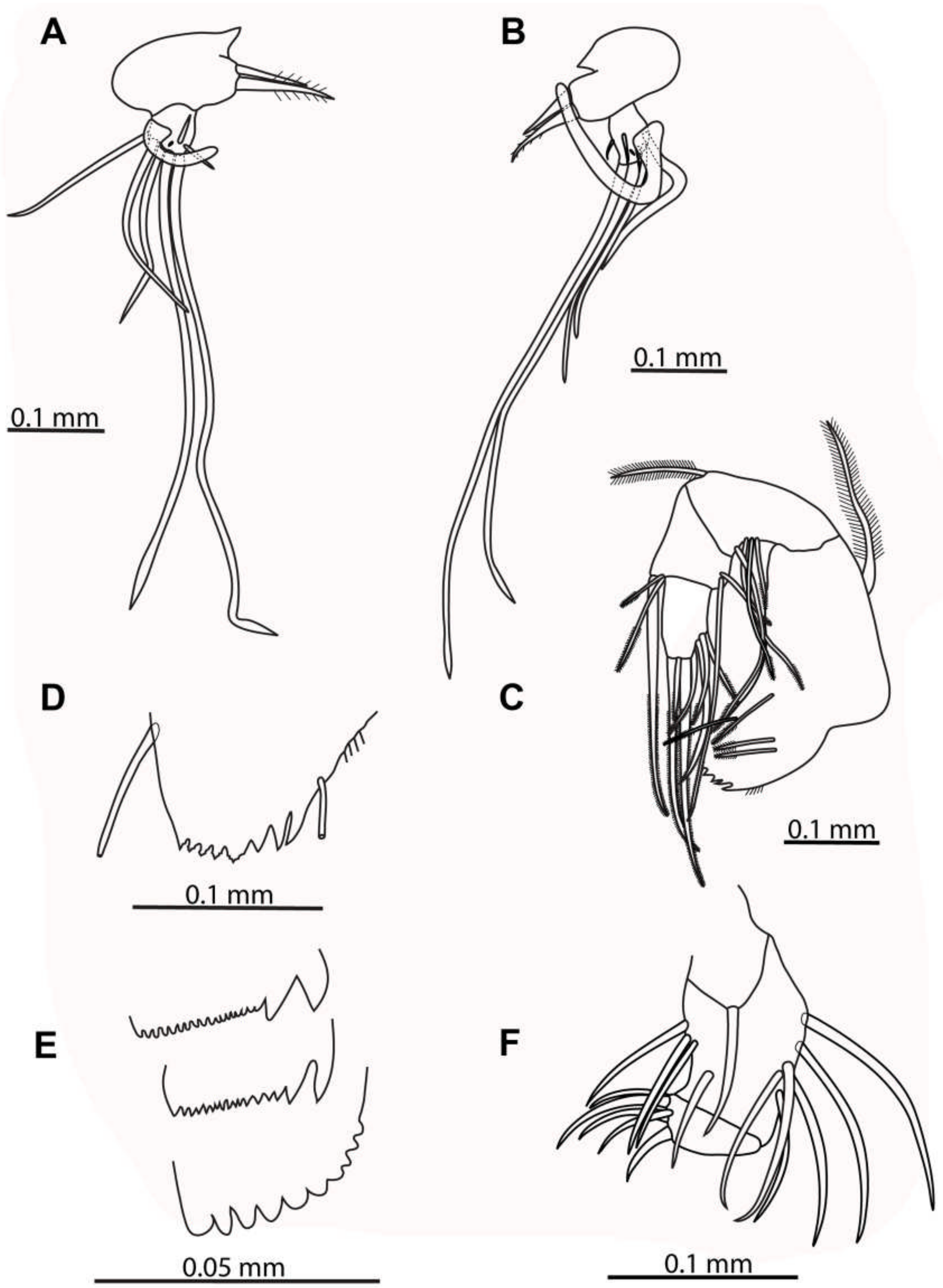


Figure 3.10. *Mamilloecia indica* male n. gen., n. sp. (A) left endopodite of second antenna, (B) right endopodite of second antenna, (C) mandible, (D) basal endite of mandible, (E) tooth lists, F. maxilla.

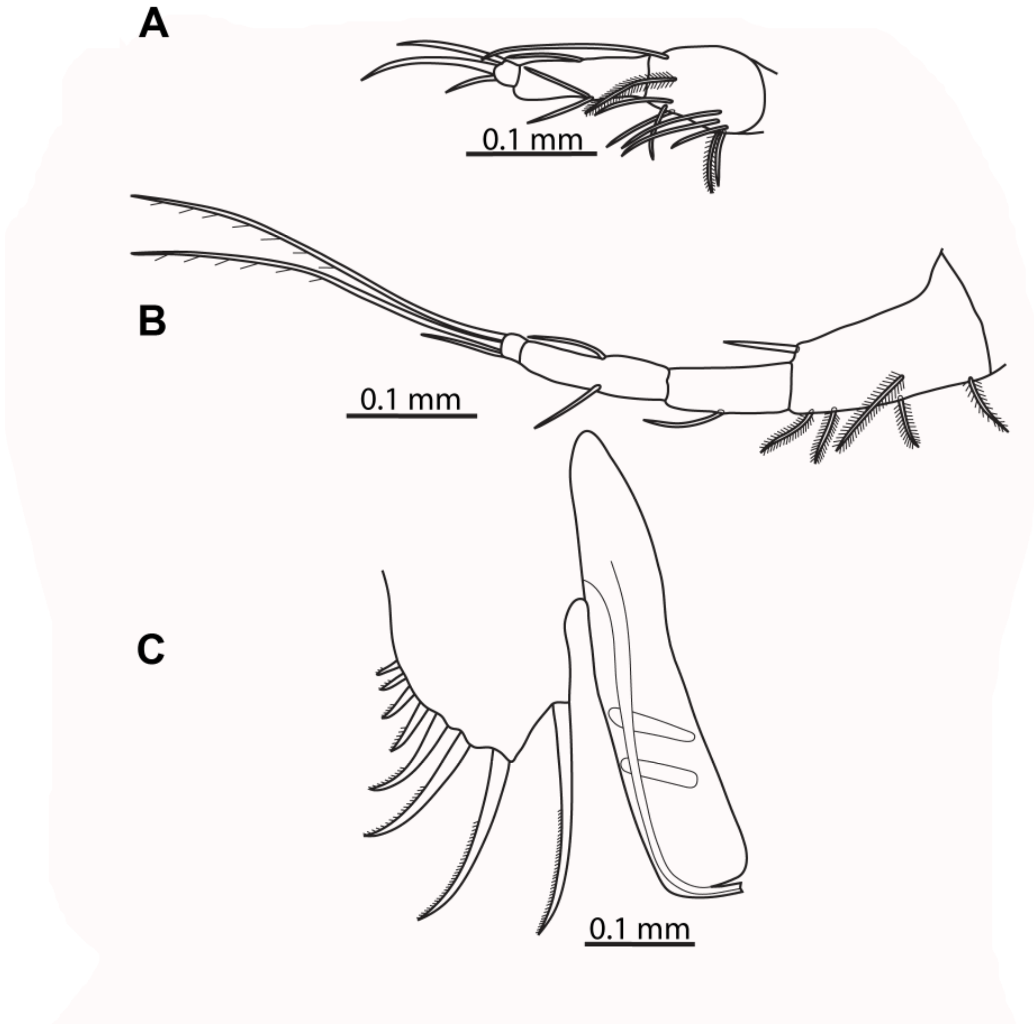


Figure 3.11. *Mamilloecia indica* male n. gen., n. sp. (A) fifth limb, (B) sixth limb, (C) caudal furca and intromittent organ.

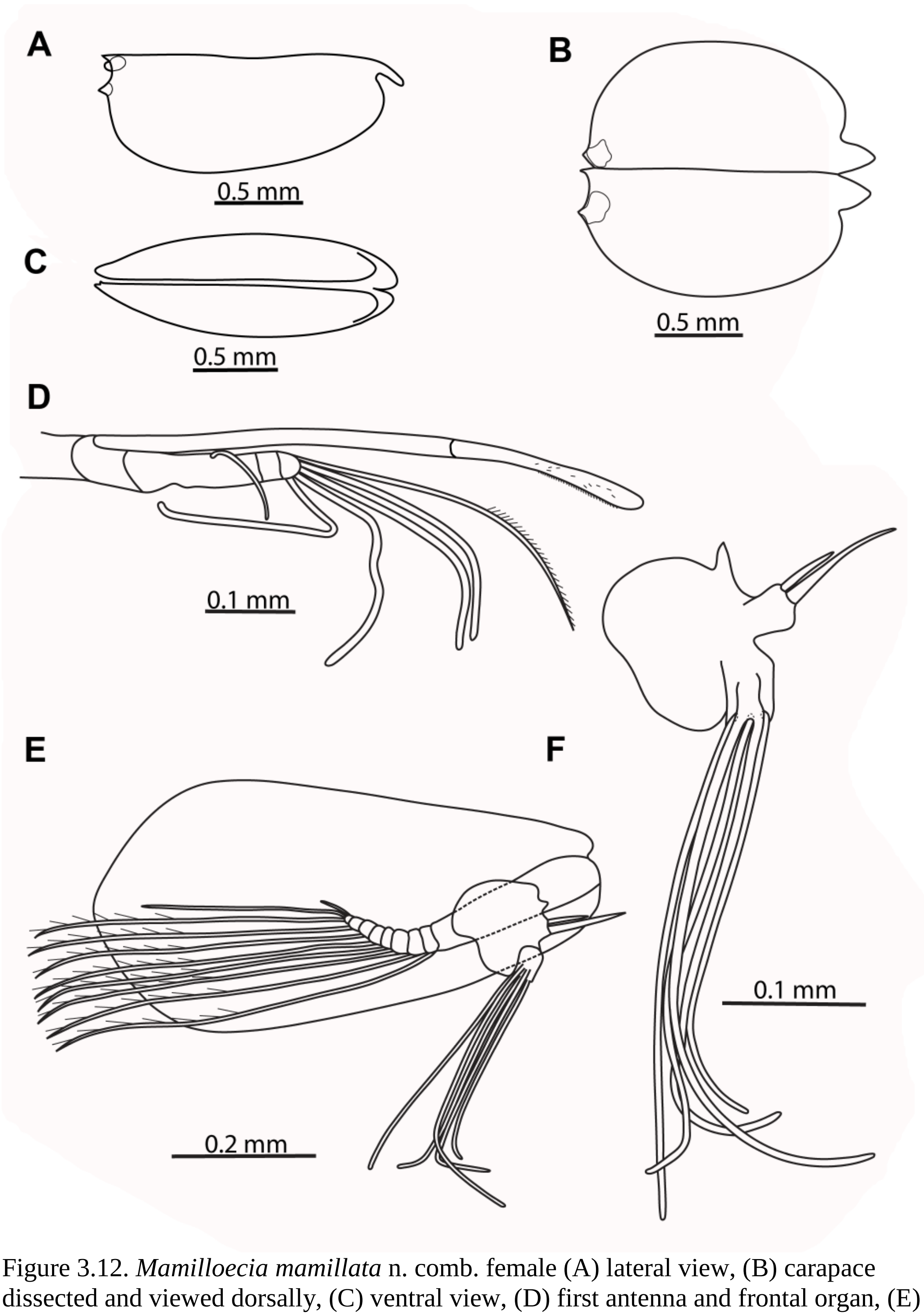


Figure 3.12. *Mamilloecia mamillata* n. comb. female (A) lateral view, (B) carapace dissected and viewed dorsally, (C) ventral view, (D) first antenna and frontal organ, (E) second antenna, (F) endopodite.

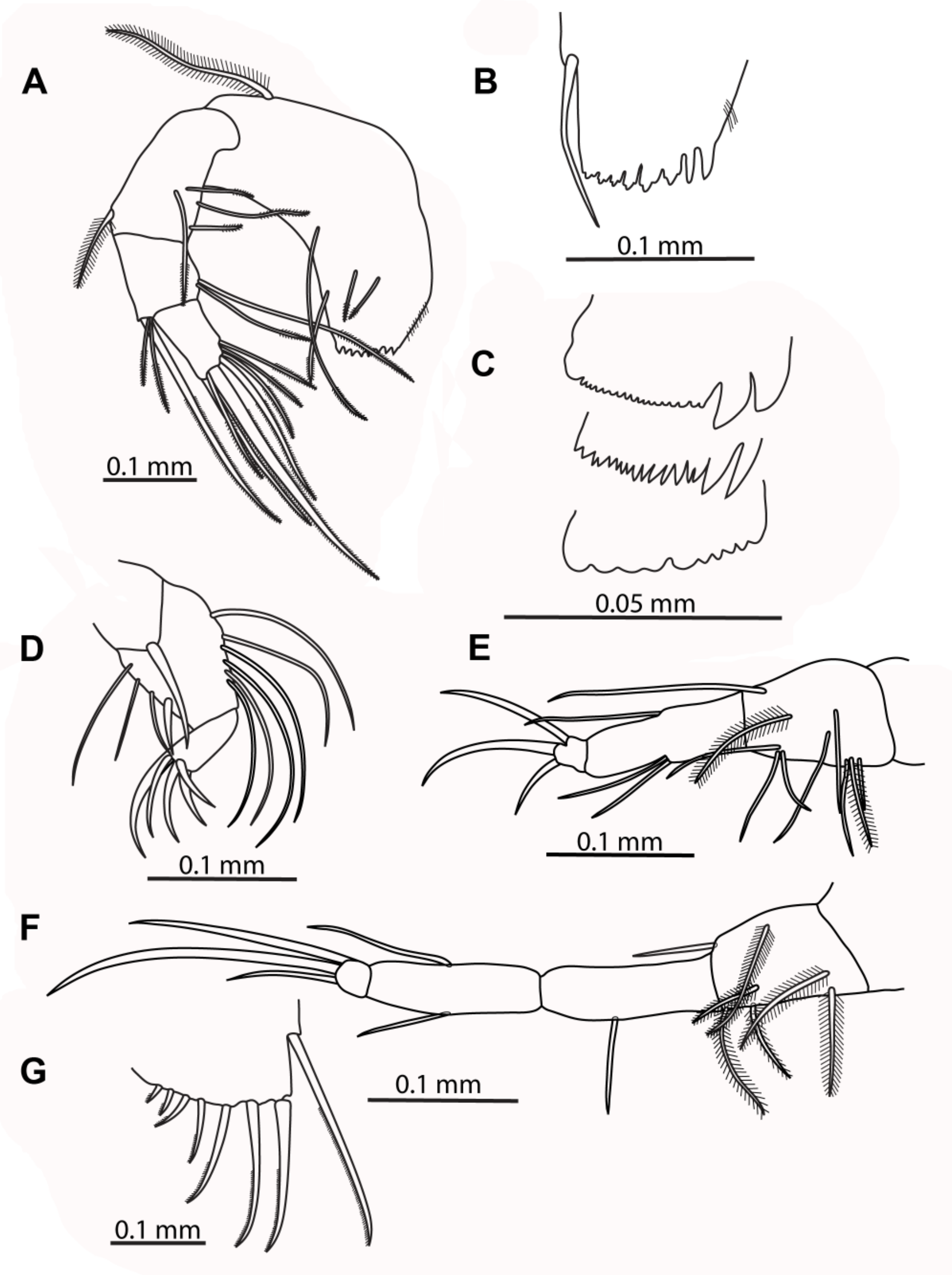


Figure 3.13. *Mamilloecia mamillata* n. comb. female (A) mandible, (B) basal endite of mandible, (C) Tooth lists, (D) maxilla, (E) fifth limb, (F) sixth limb, (G) caudal furca.

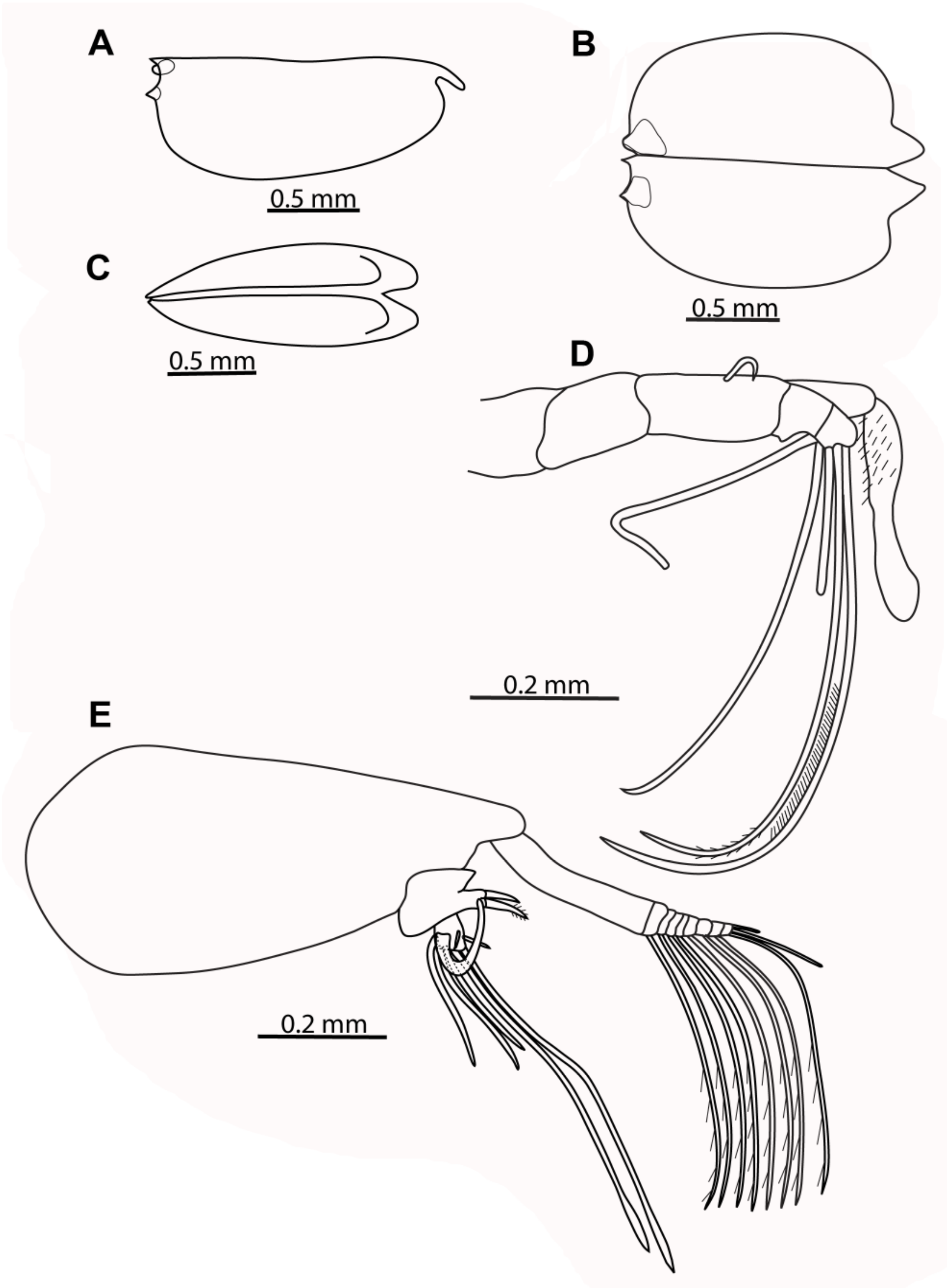


Figure 3.14. *Mamilloecia mamillata* n. comb. male (A) lateral view, (B) carapace dissected and viewed dorsally, (C) ventral view, (D) first antenna and frontal organ, (E) second antenna.

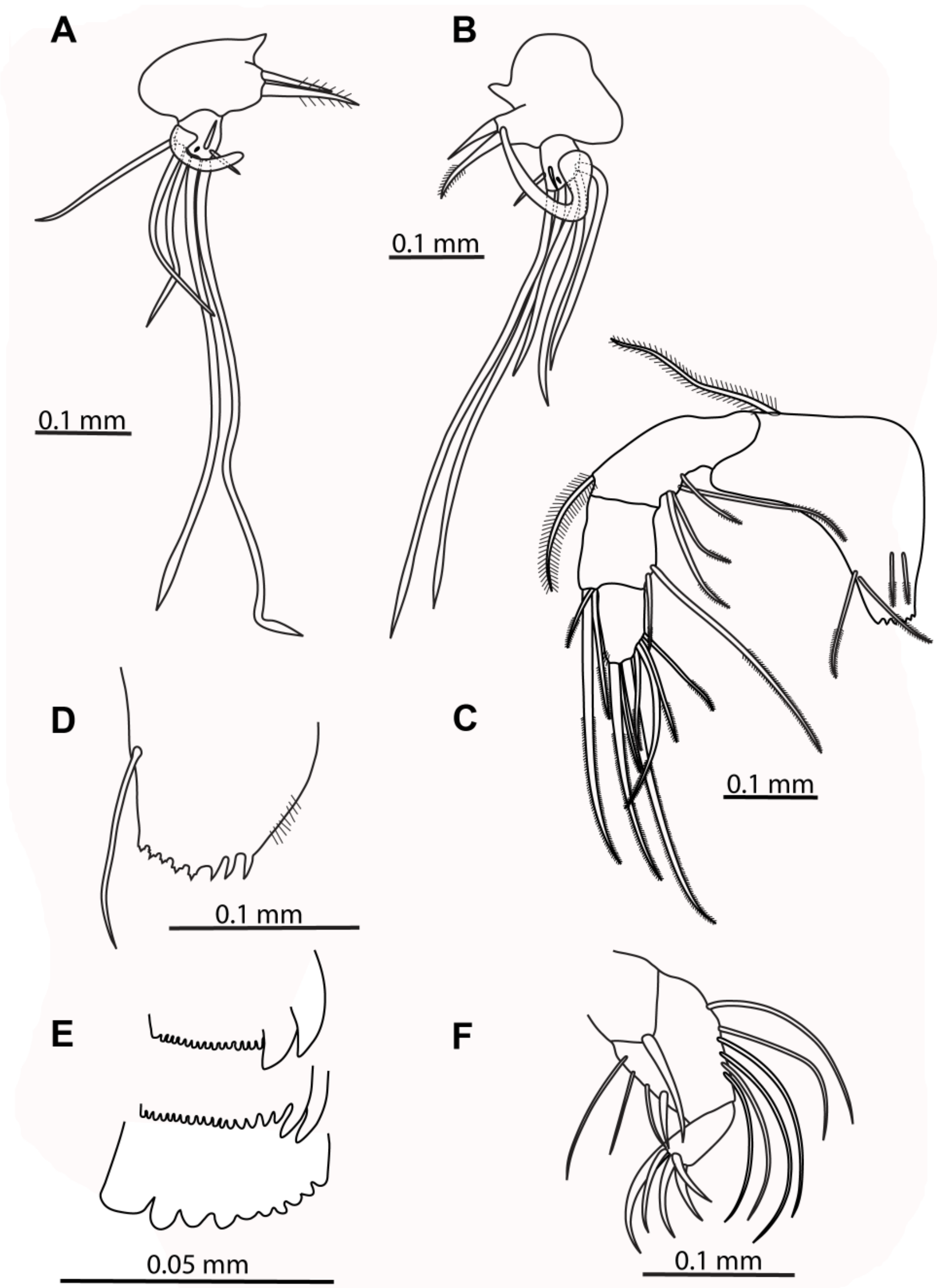


Figure 3.15. *Mamilloecia mamillata* n. comb. male (A) left endopodite of second antenna, (B) right endopodite of second antenna, (C) mandible, (D) basal endite of mandible, (E) tooth lists, (F) maxilla.

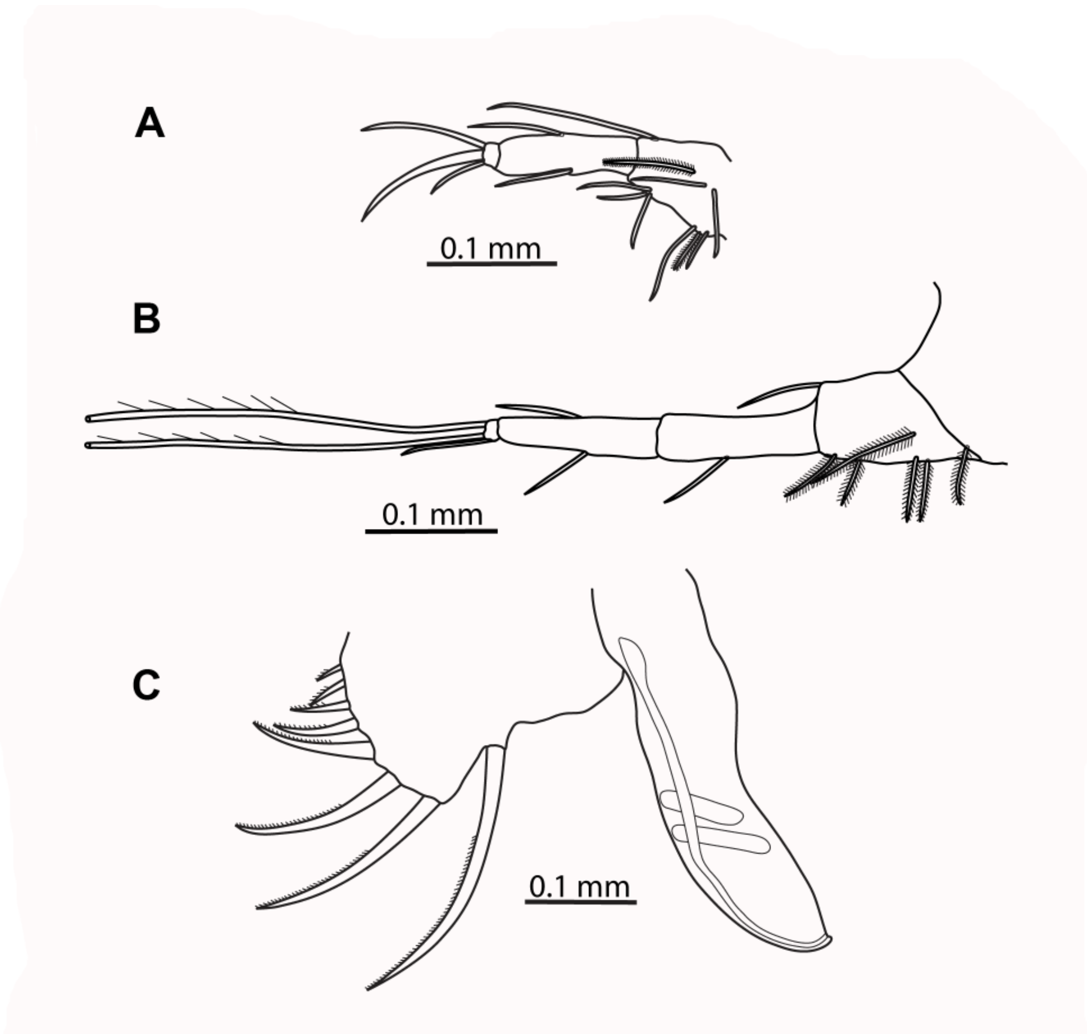


Figure 3.16. *Mamilloecia mamillata* n. comb. male (A) fifth limb, (B) sixth limb, (C) caudal furca and intromittent organ.

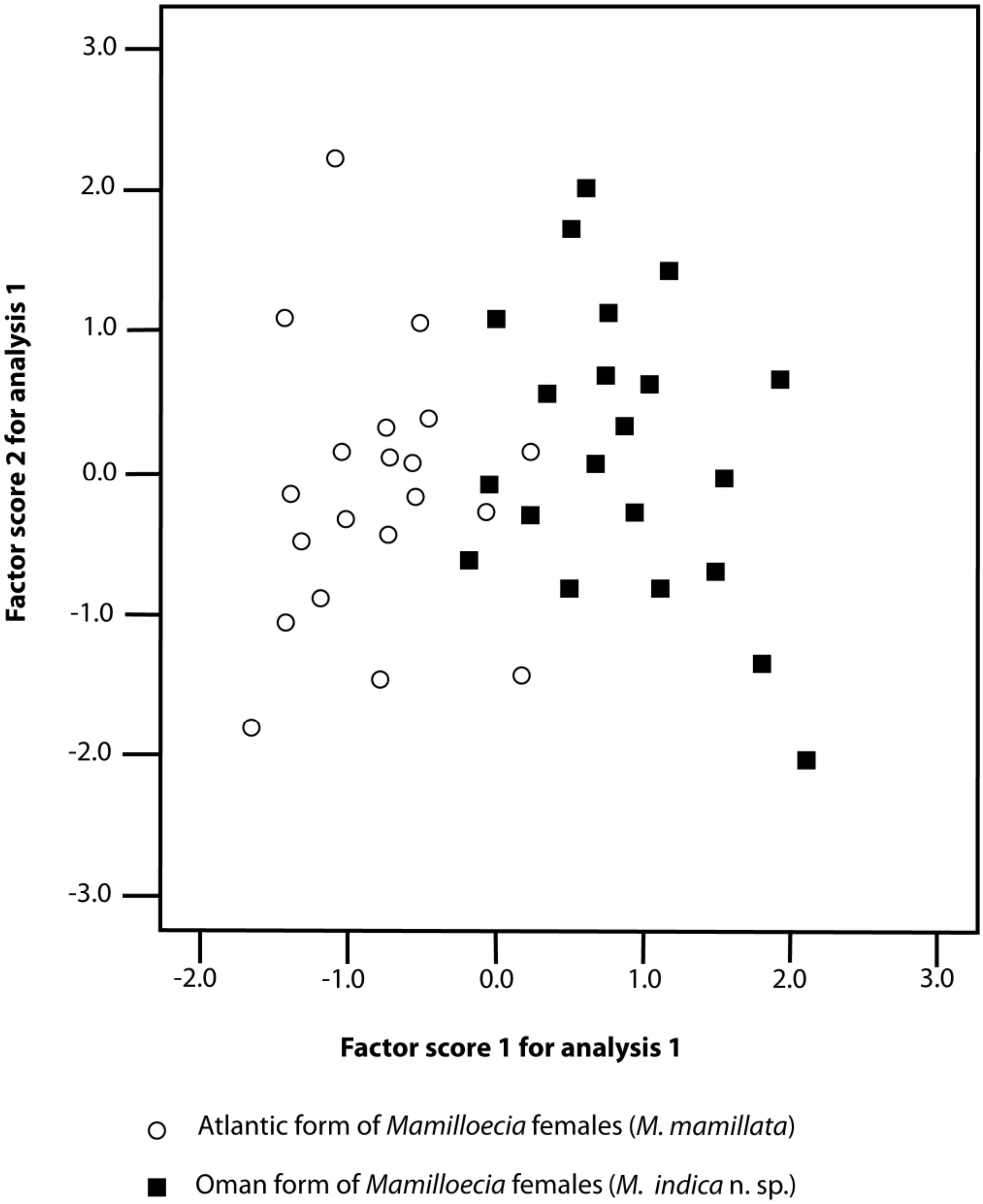


Figure 3.17. Scatterplot of principal component analysis of both forms of *Mamilloecia* females.

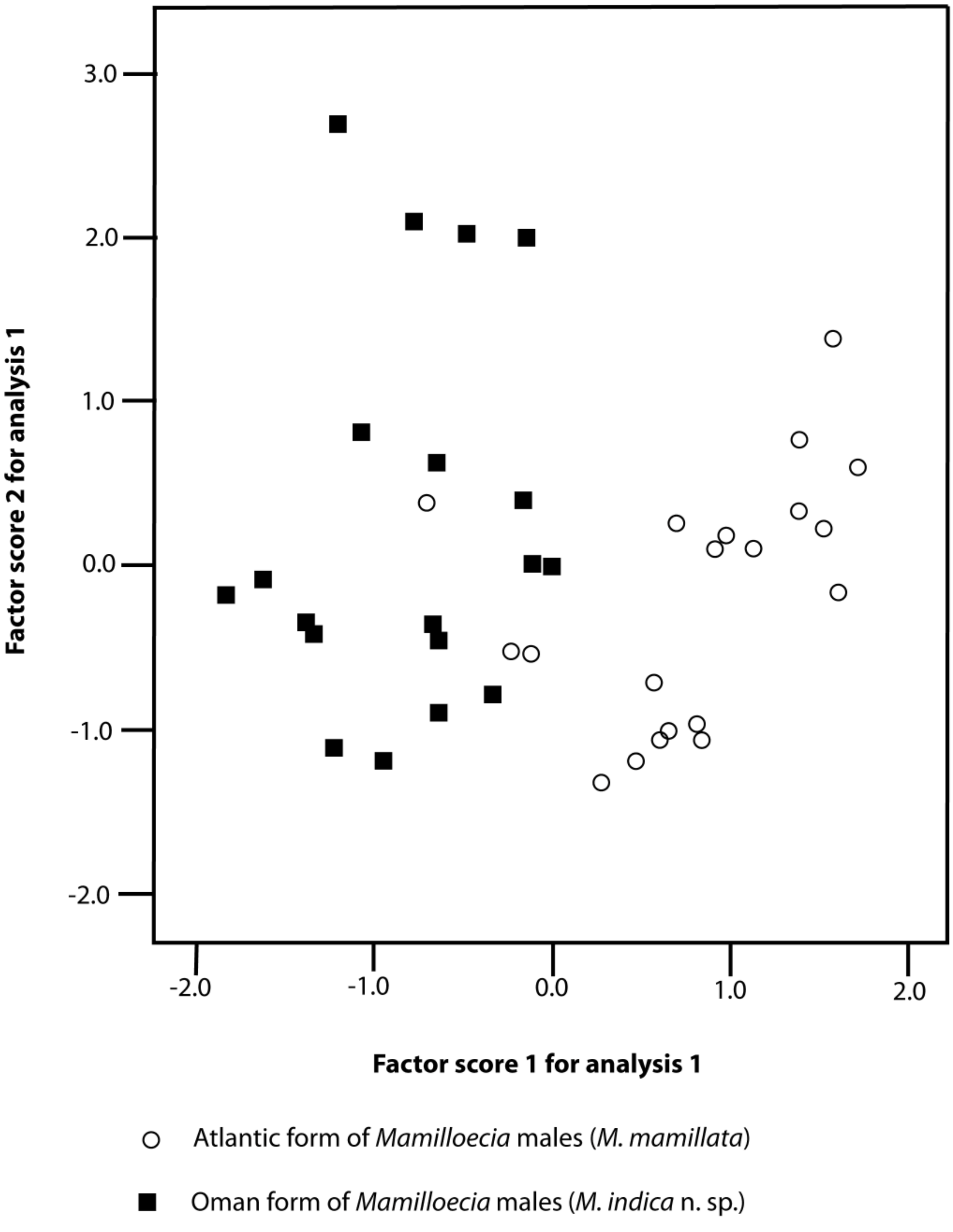


Figure 3.18. Scatterplot of principal component analysis of both forms of *Mamilloecia* males.

3.14 References

Angel MV. 1981. Ostracoda. Atlas del zooplankton del Atlantico suboccidental y metodos de trabajo con el zooplancton marino, D. Boltovskoy (ed.), Mar del Plata, Argentina: INIDEP, 543-585.

Angel MV. 1993. Pelagic Marine Ostracoda. Synopses of the British Fauna (New Series), D.M. Kermack, R.S.K. Barnes and J.H. Crothers (eds), 48, published for Linnean Society of London and The Estuarine and Coastal Sciences Association by the Field Studies Council, 1-239.

Angel MV. Blachowiak-Samolyk K. 2006. *Obtusoecia* (Halocyprida: Myodocopa: Ostracoda) a bipolar planktonic oceanic genus: taxonomy, bathymetry and zoogeographical distribution. Annales Zoologici (Warszawa), 2006, 56 (1): 1–48.

Angel MV. Blachowiak-Samolyk K. Drapun I. Castillo R. 2007. Changes in the composition of planktonic ostracod populations across a range of latitudes in the North-east Atlantic. Progress in Oceanography, 73, 1, 60-78.

Brady G.S. Norman A.M. 1896. A monograph of marine and freshwater Ostracoda of the North Atlantic and of Northwest Europe Pt II, Sections ii to iv: Myodocopa, Cladocopa, and Platycopa. Transactions of the Royal Dublin Society *(N.S.)* 5, 621-746.

Chavtur VG. 1977. Fauna of pelagic ostracods of the Halocypridae family in the northwestern part of the Pacific Ocean, Biologya Morya, 1, 28-38

Chen R. Lin J. 1995. Pelagic ostracoda in South China Seas, (In Chinese), ISBN 7-5027-4091-0/Q-115, 134.

Claus C. 1891. Die Halocypriden des Atlantisches Oceans und Mittelmeres. Alfred Hölder, Wien, 1–81.

Deevey GB. 1968. Pelagic ostracods of the Sargasso Sea off Bermuda. Bulletin of the Peabody Museum of Natural History, 26, 1-125.

Deevey G. B. 1974. Pelagic ostracods collected on Hudson 70 between the equator and 55°S in the Atlantic, Proceedings of the Biological Society of Washington, 87, 351 - 380.

Deevey GB. 1978a. A taxonomic and distributional study of the planktonic ostracods collected on three cruises of the *Eltanin* in the South Pacific and Antarctic region of the South Pacific, Biology of the Antarctic Seas, 8, Antarctic Research series, 28, 43-70.

Deevey GB. Brooks, AL. 1980. The planktonic ostracods of the Sargasso Sea off Bermuda: Species composition and vertical and seasonal distribution between the surface and 2000 m. Bulletin of the Florida State Museum Biological Sciences, 26, 37-124.

Granata L. Caporiacco L. 1949. Ostracods marins recuellis pendant les croissières du Prince Albert 1 er de Monaco. Resultats des campagnes, Scientific Prince Albert 1 er, 109. 1-51.

Herring PJ. Howell PR. Roe HSJ. 1998. Scheherezade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb – 30 Apr 1997. No11. Biomass data. Leg 1, 12 Feb – 19 Mar 1997 (Unpublished manuscript).

Herring PJ. Howell PR. Pugh PR. 1999. Scheherezade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb – 30 Apr 1997. No 16, Fish, decapod shrimps and siphonophores: abundances and size data. Leg1. 12 Feb – Mar 1997 (Unpublished manuscript).

Hoskin CJ. Higgie M. 2008. A new species of velvet gecko (Diplodactylidae: Oedura) from north-east Queensland, Australia. Zootaxa, 1788, 21-36.

Iles EJ. 1953. A preliminary report on the Ostracoda of the Benguela Current, Discovery Report, 26, 259-280.

Leveau M. 1965. Contribution a l’ étude des Ostracodes et Cladocères du Golfe de Marseille, Recueil des travaux de la Station Marine d’Endoumme-Marseille (Fax. hors. série. suppl.), 37, 161-243.

Leveau M. 1967. Ostracodes pélagique du sud-ouest de l’Océan Indien (Région de Tuléar). Recueil des travaux de la Station Marine d’Endoumme-Marseille (Fax. hors. série. suppl.), 6, 63 – 70.

Müller GW. 1906a. Ostracoda. Wissenschaftliche Ergebnisse der Deutschen Tiefsee-Expedition ‘*Valdivia’* 1989 – 1899, 8, 29–154.

Müller G.W. 1906b. Die Ostracoden der deutschen Südpolar-Expedition 1901 – 1903, Deutsche Südpolar-Expedition 1901 – 1903, 10, (Zoology 2), 51-182.

Müller GW. 1912. Ostracoden. Das Tierreich, 31, 1–434.

Poulsen EM. 1973. Ostracoda-Myodocopa, 3b. Halocypriformes-Halocypridae. Conchoeninae. Dana Report, 84, 1-223.

Roe HSJ. Shale DM. 1979. A new multiple rectangular midwater trawl (RMT1+8) and some modifications to the Institute of Oceanographic Sciences’ RMT1+8. Marine Biology, 50, 283–288.

Roe HSJ. Baker AdeC. Carson RM. Wild RA. Shale DM. 1980. Behaviour of the Institute of Oceanographic Sciences' rectangular midwater trawls; theoretical aspects and experimental observations. Marine Biology, 56, 247-259.

Rudyakov Y.A.. 1962. Ostracoda Myodocopa (family Halocypridae) from the N.W. Pacific Ocean, Trudy Instituta Okeanologii, 58, 172-201.

Schwartz SS. Innes DJ. Herbert PDN. 1985. Morphological separation of *Daphnia pulex* and *Daphnia obtusa* in North America. Limnology and Oceanography, 30, 189-197.

Skogsberg T. 1920. Studies on marine ostracods. Part 1. (Cypridinids, halocyprids and polycopids). Zoologiska Bidrag Fran Uppsala, Supplement 1, 1–784.

Vavra V. 1906. Die Ostracoden (Halocypriden und Cypridiniden) der Plankton-Expedition, Ergebnisse Plankton-Expedition Humboldt-Stiftung, 2, 1-76.

Chapter 4

Description of a new genus *Huxleyoecia* (Halocyprididae, Ostracoda) and a new species, *H. muscatensis*, from the Gulf of Oman

4.1 Abstract

During the analysis of a bathymetrically stratified series of zooplankton samples collected from the upwelling region of the Gulf of Oman, during February 1997, the samples collected from 1800 – 2000 m were found to contain specimens of a novel species. This species superficially resembled *Conchoecia* species, but detailed morphological analysis shows that it differs significantly not only from the genus *Conchoecia* but also from all other Conchoeciinae genera. A novel species is described and attributed to a novel genus *Huxleyoecia* and is designated the type species.

4.2 Introduction

During the northeast monsoon season of 1997 a research cruise to the Gulf of Oman was undertaken to investigate the influence of upwelling on biological processes. A component of the study was the collection of a day and night bathymetrically stratified series of horizontal tows using the multiple rectangular midwater trawl (RMT1+8) net system (Roe and Shale 1979, Roe et al. 1980) at an oceanic station (*Discovery* 54001, 24° 12'N, 58° 40'E). The planktonic ostracods were sorted from the RMT 1 (mesh size 0.33 mm) samples and analysed for bathymetric distribution and species composition.

Halocyprid ostracods, the most abundant of oceanic ostracods, are small crustaceans in marine mesozooplankton communities. They feed on debris sinking from the surface and consequently are ecologically important in the food chain and carbon cycle (Angel et al. 2007).

The 1800 – 2000 m samples contained a distinct form of halocyprid ostracod that could not be assigned to any known genus and was identified as being new. In this chapter this species is described in detail and a new genus, *Huxleyoecia* is established to accommodate it. This species *H. muscatensis* is designated as the type for this currently monotypic genus.

4.3 Materials and Methods

The zooplankton samples obtained during the R.R.S. *Charles Darwin* “Scheherezade” cruise of 1997, during the northeast monsoon, were fixed on board the ship in 5 % seawater formalin. After 24 h the zooplankton was moved into a preserving fluid of 0.5 % propylene phenoxetol, 4.5 % propylene glycol, 5 % formalin seawater solution. These zooplankton samples were initially stored at the National Oceanography Centre, Southampton, but in 2006 the zooplankton samples were moved to the Natural History

Museum, London for analysis. The preserving fluid was replaced by 80 % industrial methylated ethanol and the halocyprid ostracods from the samples were picked out and sorted to species.

An exemplar female and an exemplar male were selected as holotype and allotype. Each exemplar specimen was measured for length, breadth and height before being placed on a cavity slide in lactophenol containing lignin pink and dissected under a stereo-microscope. The carapace, antennae and limbs were mounted as temporary preparations in lactophenol and examined under an Olympus BH2 compound microscope using differential interference contrast. A set of measurements of the antennae, limbs and setae (Angel and Blachowiak-Samolyk 2006) was made. The measurements were expressed as percentages of the individual carapace lengths to standardise them and morphological characteristics were recorded. Using a camera lucida, pencil drawings were made of the complete animal and individual dissected parts. These drawings were scanned, re-drawn using Adobe Illustrator and collated into plates using Adobe Photoshop. Skogsberg's (1920) nomenclature for the structure and setation of the antenna, mandible, maxilla, 5th limb, 6th limb, and caudal furca has been used throughout.

4.4 Systematics

Class **OSTRACODA** Latreille, 1802

Subclass **MYODOCOPA** Sars, 1866

Order **HALOCYPRIDA** Dana, 1853

Suborder **HALOCYPRIDINA** Dana, 1853

Family **HALOCYPRIDIDAE** Dana, 1853

Subfamily **CONCHOECIINAE** Claus, 1891

Genus ***Huxleyoecia*** Graves gen. nov.

4.5 Diagnosis of *Huxleyoecia* n. gen.

Carapace lacking in sculpture; rostra well developed equal in length; antero-ventral margin smoothly curving. Right valve asymmetrical gland opening at posterior ventral corner; left valve asymmetrical gland opening at posterior dorsal corner. Frontal organ sexually dimorphic: female stem longer than limb of first antenna, undifferentiated from curving capitulum with spinules along dorsal and ventral edges; male, stem subequal to limb of first antenna with clear suture demarcating the capitulum. Capitulum angled down, with spinules along ventral edge, end rounded. Female first antenna e-seta bearing long spinules basally; male first antenna b-seta bearing double row of approximately nine pairs of spinules pointing distally; e-seta with between thirty and forty pairs of spinules on posterior margin pointing basally. Second antenna female lacking c-, d- or e-setae; endopodite g-setae distally sword-shaped; male right "hook" wider and longer than left "hook"; g-seta distally sword-shaped. Mandible with dorsal seta of first segment female bare; male plumose; longest claw approximately one fifth of carapace length. Maxilla basal segment bearing six bare anterior setae, one lateral seta and three posterior setae; distal segment bearing two claw setae and three normal setae. Sixth limb sexually dimorphic; terminal segment of male with three long subequal setae with fine hairs distally.

Etymology The genus is named after the biologist T.H. Huxley and *–oecia* the standard ending for the majority of genera of the subfamily Conchoeciinae.

Type species: *Huxleyoecia muscatensis* Graves, by original designation.

4.6 *Huxleyoecia muscatensis* sp.nov.

(Figures 1 – 5)

Type material

Permanent preparations of the dissected holotype and allotype are deposited in the collections of the Natural History Museum, London registration number NHMUK 2011.8009 for the holotype (female) on four slides and NHMUK 2011.8010 for the allotype (male) on four slides. The remaining 38 female and 12 male paratypes are retained in 80% industrial methylated ethanol registration numbers NHMUK 2011.8011 - 20

Etymology The specific name refers to the capital city of Oman close to the type locality.

Description The morphological characters of the carapaces and internal structures are listed in Tables 4.1 to 4.10.

Female

Carapace (Figures 4.1 A, B, C) Mean length 1.96 ± 0.04 mm (n = 38). Carapace of exemplar specimen (holotype) (Table 4.1) length 1.98 mm; height 0.84 m; breadth 0.80 mm. Height:length ratio 42.4 %CL, breadth:length ratio 40.4 %CL. In lateral view carapace unsculptured. Carapace maximum height at mid-length. Ventral margin curving smoothly into posterior margin. Opening of asymmetrical gland at posterior ventral corner of right valve; left valve asymmetrical gland opening on dorsal margin near posterior dorsal corner, just anterior to posterior end of hinge between two valves of the carapace valves.

Frontal organ (Table 4.1; Figure 4.1 D) Frontal organ stem slender, almost straight and considerably longer than first antenna. Capitulum not demarcated from stem by suture, curving ventrally with pointed end: small number of spinules on dorsal edge; small spinules along most of ventral edge. Total length 31.0 %CL.

First antenna (Table 4.2; Figure 4.1 D) Clearly five-segmented. Total limb length 15.7 %CL. Black pigmented spots visible in segments 1 – 3; third segment with bare dorsal seta 10.2 %CL. Fifth segment with five unequal setae; a-seta 16.2 %CL; b-seta 20.1 %CL; c-seta 20.7 %CL; d-seta 21.3 %CL; e-seta 41.7 %CL with long spinules basally on anterior margin.

Second antenna (Table 4.2; Figure 4.1 E) Protopodite 35.4 %CL. First exopodite segment with small terminal seta, about half length of protopodite. Most swimming setae similar in length to protopodite, all but shortest seta with long hairs distally. Endopodite (Figure 4.1 F) on first segment short, pointed a-seta; b-seta pointed and bare; second segment with no c-, d- or e-setae; f-seta 31.8 %CL; g-seta with sword-shaped tip 43.2 %CL; h-seta 18.2 %CL; i-seta 27.0 %CL; j-seta 25.3 %CL.

Mandible (Table 4.3; Figure 4.2 A) Coxale toothed edge of pars incisiva with ten large blunt teeth (Figure 4.2 C). Distal tooth list with two large and approximately thirteen small pointed teeth. Proximal tooth list slightly narrower, with one large tooth, two small teeth, one large tooth and approximately nine small pointed teeth. Outer margin of toothed edge of basal endite (Figure 4.2 B) with two large dagger-shaped teeth, second with rounded tip, and six subserrate teeth. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with bare dorsal seta and four finely spinose ventral setae. Second segment with two ventral and three dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla (Table 4.3; Figure 4.2 D) Basal segment with six anterior, one lateral and three posterior setae. Distal segment comparatively short and wide with five bare terminal claw setae.

Fifth limb (Table 4.4; Figure 4.2 E) Ventrally basale with one plumose and five bare setae, laterally one plumose and three bare setae, dorsally single long seta – remnant of exopodite. First endopodite segment with two ventral setae and one dorsal seta, all bare. Second segment with three unequal, curved terminal claw setae; middle claw longest 7.7 %CL.

Sixth limb. (Table 4.5; Figure 4.2 F) Basale with five plumose ventral setae, laterally three plumose setae and one plumose seta dorsally. First endopodite segment with one ventral spinose seta. Second segment with one spinose seta ventrally and one dorsally. Third segment with three unequal spinose, terminal claw setae; middle claw longest 9.6 %CL.

Caudal furca (Table 4.5; Figure 4.2 G) Eight pairs of unilaterally spinulose claw setae diminishing in size dorsally; longest claw 13.1 %CL.

Male

Carapace (Figures 4.3 A, B, C) Mean length 1.75 ± 0.04 mm (n = 12). Carapace of exemplar specimen (Table 4.6) length 1.66 mm; height 0.84 mm; breadth 0.70 mm. Height:length ratio 50.6 %CL, breadth:length ratio 42.2 %CL. In lateral view carapace unsculptured as in female, maximum height just anterior to mid-length. Ventral margin curving smoothly into posterior margin. Opening of asymmetrical gland at posterior ventral corner of right valve; left valve asymmetrical gland opening on dorsal margin near posterior dorsal corner, just anterior to posterior end of hinge between carapace valves.

Frontal organ (Table 4.6; Figure 4.3 D) Frontal organ stem straight; just longer than first antenna. Capitulum long, with rounded distal end. Dorsal surface with few spinules proximally; ventral surface with spinules along most of surface. Total length 47.6 %CL, much longer than first antenna.

First antenna (Table 4.7; Figure 4.3 D) Clearly five segmented. Limb length 38.3 %CL. Black pigmented spots visible in segments 1and 2; third segment with short, coiled dorsal seta 3.9 %CL. Fifth segment with five unequal setae; a-seta with swollen base 13.0 %CL; b-seta 42.9 %CL with 18 downward pointing spinules; c-seta 12.3 %CL; d-seta 45.2 %CL; e-seta 54.2 %CL with 33 pairs of closely-spaced, sharp spinules on posterior margin pointing basally.

Second antenna (Table 4.7; Figure 4.3 E) Protopodite 47.4 %CL. First exopodite segment about half length of protopodite, armed with small terminal seta. All swimming setae shorter than protopodite, all but shortest seta with long hairs distally. Endopodite with short, pointed, bare a-seta and long b-seta pointed with hairs on first segment; second segment c-, d-, and e-setae, all very short; f-seta 39.8 %CL; g-seta sword-shaped distally 43.1 %CL; h-seta short 7.2 %CL; i-seta 19.9 %CL; j-seta 11.4 %CL. Endopodite asymmetrical: right endopodite (Figure 4.4 B) with elongated clasping organ in form of hook with long proximal shank and very long curved end piece 10.2 %CL. Left endopodite (Figure 4.4 A) ‘hook’ shorter 9.8 %CL.

Mandible (Table 4.8; Figure 4.4 C) Coxale toothed edge of pars incisiva with ten large blunt teeth (Figure 4.4 E). Distal tooth list with two large and approximately thirteen small pointed teeth. Proximal tooth list slightly narrower, with one large tooth, two small teeth, one large tooth and approximately nine small pointed teeth. Outer margin of toothed edge of basal endite (Figure 4.4 D) with two large dagger-shaped teeth, second with rounded tip, and six subserrate teeth. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with plumose dorsal seta and four finely spinose ventral setae. Second segment with two ventral and three dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla and Fifth limb (Tables 4.8, 4.9; Figures 4.4 F, 4.5 A) Structure and arrangement of setae as in female.

Sixth limb (Table 4.10; Figure 4.5 B) Basale with five plumose setae ventrally, three lateral plumose setae and one plumose dorsal seta. First endopodite segment with single, ventral seta. Second endopodite segment with one seta ventrally and one dorsally. Third segment with three very long terminal setae, subequal and evenly curved, with long hairs. 52.0 %CL.

Caudal furca (Table 4.10; Figure 4.5 C) Structure and arrangement of furcal claws similar to female; longest claw 16.9 %CL.

Intromittent organ (Table 4.10; Figure 4.5 C) Male copulatory appendage 28.3%CL, long, narrow with rounded tip and six oblique muscles.

4.7 Discussion

The new genus *Huxleyoecia* is closest to the genus *Conchoecia* Dana, 1849 as the carapace is slightly elongated, with a straight posterior margin and a rounded posterior dorsal corner. However, *Huxleyoecia* differs from *Conchoecia* as the ventral margin is slightly convex rather than slightly concave as in *Conchoecia* and the anterior margin of *Huxleyoecia* is less rounded.

In *Huxleyoecia* the first antenna has pigmentation in segments 1 and 2, and segment 3 in female. The ventral surface lacks spinules, the third segment bears the dorsal seta which in the female is bare, this is in contrast to *Conchoecia* where the first antenna has no pigmentation, there are a few small spinules on the ventral edge close to the insertion of the e-seta and the second segment bears the dorsal seta which in the female is plumose. In female, *Huxleyoecia muscatensis* the e-seta on the first antenna is twice as long as the other setae with long spinules basally on anterior margin, whereas the length of the e-seta of *Conchoecia magna* Claus, 1874 (the type species of *Conchoecia*) is three times the length of the other setae and bears spinules distally along its posterior margin. In male *H. muscatensis* the b-seta bears approximately eighteen downward pointing spinules, the d-seta is bare and the e-seta bears between thirty and forty pairs of closely-spaced, sharp spinules on posterior margin pointing basally, whereas in *C. magna* both the b-seta and the d-seta bear fine spinules and the e-seta bears forty two to fifty spinules pointing basally.

In the second antenna of female *H. muscatensis* the a- and b-setae on the first endopodite are bare; the male a-seta is bare with the b-seta bearing hairs along its length. The a- and b-setae on the female endopodite of *C. magna* each bear strong spines; the male a-seta is bare, but the b-seta bears long hairs basally. In both sexes of *H. muscatensis* the f-, g- h-, i-, j-setae are bare, but the g-seta is sword-shaped distally. In both sexes of *C. magna* the f- and g-setae bear a few spinules along their length. In male *H. muscatensis* the right clasping organ is in the form of a hook with long proximal shank and very long end piece curving upwards at an acute angle; terminating in a rounded end. The left hook is shorter and thinner with a rounded end. In *C. magna* the right hook turns a sharp 90º angle close to its base, curves through a further 90º half way along its length and terminates at a point. The left hook is angled at 90º at its base and then runs straight to a pointed tip. Both right and left hooks are ornamented with papillae near the terminal ends. The mandible of the male *H. muscatensis* first endopodite segment bears a plumose dorsal seta similar to *Conchoecia hyalophyllum*

Claus, 1891. The males of all *Conchoecia* species, but *Conchoecia hyalophyllum,* have a bare dorsal seta on the first endopodite segment.

Ecologically *H. muscatensis* is a deep living species, that is below 1600 m and shows no vertical migration, whereas the majority of the *Conchoecia* species occur above 1500 m.

4.8 Tables and Figures

Table 4.1. Measurements of female *Huxleyoecia muscatensis* (n = 1, %CL = Carapace Length, PDC = posterior dorsal corner, PVC = posterior ventral corner).

	Number / Comment	Length mm / % Ratio
Carapace		
length		1.98
height		0.84
breadth		0.8
height/length %		42.4%
breadth/length %		40.4%
PDC, left tip to posterior hinge (% CL)		2.0%
PDC, right tip to posterior hinge (% CL)		2.0%
rostrum, left tip to anterior hinge (% CL)		16.7%
rostrum, right tip to anterior hinge (% CL)		16.7%
incisure, left rostrum tip to inner edge (% CL)		13.4%
incisure, right rostrum tip to inner edge (% CL)		12.6%
opening of left gland	PDC	
opening of right gland	PVC	
Frontal organ		
capitulum length (% CL)		11.6%
stem length (% CL)		19.4%
total length (% CL)		31.0%
length relative to antenna 1	much longer	

Table 4.2. Measurements of female *Huxleyoecia muscatensis* (n = 1, %CL = Carapace Length).

	Number / Comment	% Ratio
Antenna 1		
length segment 1 (% CL)	black pigment	7.4%
length segment 2 (% CL)	black pigment	6%
length segment 3 (% CL)		1.1%
length segment 4 (% CL)		1.3%
length segment 5 (% CL)		0.3%
total length (% CL)		16%
a-seta (% CL)		16.2%
b-seta (% CL)		20.1%
c-seta (% CL)		20.7%
d-seta (% CL)		21.3%
e-seta (% CL)	spinules	41.7%
dorsal seta		10.2%
Antenna 2		
protopodite (% CL)		35.4%
exopodite 1 (% CL)		19.2%
exopodite 2 -9 (% exopodite 1)		36.8%
longest swimming seta (% CL)		35.1%
mid-length swimming seta (% CL)	hairs	21.5%
shortest swimming seta (% CL)	bare	9.8%
endopodite segment 1 (% CL)		8.5%
a-seta	bare	2.3%
b-seta	bare	4.7%
endopodite segment 2 (% CL)		2.9%
f-seta (% CL)		31.8%
g-seta (% CL)		43.2%
h-seta (% CL)		18.2%
i-seta (% CL)		27.0%
j-seta (% CL)		25.3%

Table 4.3. Measurements of female *Huxleyoecia muscatensis* (n = 1, %CL = Carapace Length).

	Number / Comment	% Ratio
Mandible		
basale		
endopodite segment 1 dorsal setae	1 bare	
endopodite segment 1 ventral setae	4	
endopodite segment 2 dorsal setae	3	
endopodite segment 2 ventral setae	2	
endopodite segment 3 terminal setae	7	
endopodite segment 3 longest claw (% CL)		19.2%
endopodite segment 3 longest claw (% limb)		100.0%
teeth on basal endite	2 + 6	
pars incisiva	10	
distal tooth list	2 + 13	
proximal list	1 + 2 + 1 + 9	
setae laterally on endite	2 + 2	
exopodite	1 plumose	
limb length (%CL)		19.2%
Maxilla		
basal segment anterior setae	6	
basal segment lateral setae	1	
basal segment posterior setae	3	
terminal spines	0	
distal segment claw setae	2	
distal segment normal setae	3	

Table 4.4. Measurements of female *Huxleyoecia muscatensis* (n = 1, %CL = Carapace Length).

	Number / Comment	Length mm / % Ratio
Fifth limb		
basale ventral setae	3 + 2 + 1 plumose	
basale lateral setae	3 + 1 long plumose	
basale dorsal setae	1 long	
endopodite segment 1 ventral setae	2	
endopodite segment 1 dorsal setae	1	
height		0.03
length		0.143
height/length %		21.1%
endopodite terminal setae		0.065
		0.153
		0.12
longest terminal seta % CL		7.7%
length of segment 2		0.0%
longest seta/length segment 2		288.9%
length of limb		0.290
longests seta/ length limb		22.4%

Table 4.5. Measurements of female *Huxleyoecia muscatensis* (n = 1, %CL = Carapace Length).

	Number / Comment	Length mm / % Ratio
Sixth limb		
basale ventral setae	2 + 2 + 1 all plumose	
basale lateral setae	2 + 1 all plumose	
basale dorsal setae	1 plumose	
endopodite segment 1 ventral setae	1	
endopodite segment 1 dorsal setae	0	
endopodite segment 2 ventral setae	1	
endopodite segment 2 dorsal setae	1	
height		0.4
length		0.155
segment 2 height /length %		25.8%
endopodite segment 3 terminal setae		0.190
		0.290
		0.130
limb length		0.490
longest seta % CL		9.6%
longest seta % segment 2		122.6%
longest seta % limb		146.2%
Caudal furca		
paired claws		0.260
		0.220
		0.175
		0.140
		0.105
		0.080
		0.060
		0.045
longest claw % CL		13.1%

Table 4.6. Measurements of male *Huxleyoecia muscatensis* (n = 1, %CL = Carapace Length, PDC = posterior dorsal corner, PVC = posterior ventral corner).

	Number / Comment	Length mm / % Ratio
Carapace		
length		1.660
height		0.840
breadth		0.700
height/length %		50.6%
breadth/length %		42.2%
PDC, left tip to posterior hinge (% CL)		6.0%
PDC, right tip to posterior hinge (% CL)		6.6%
rostrum, left tip to anterior hinge (% CL)		17.5%
rostrum, right tip to anterior hinge (% CL)		17.5%
incisure, left rostrum tip to inner edge(% CL)		16.3%
incisure, right rostrum tip to inner edge (% CL)		14.8%
opening of left gland	PDC	
opening of right gland	PVC	
Frontal organ		
capitulum length (% CL)		16.6%
stem length (% CL)		31.0%
total length (% CL)		47.6%
length relative to antenna 1	stem significantly longer	

Table 4.7. Measurements of male *Huxleyoecia muscatensis* (n = 1, %CL = Carapace Length).

	Number / Comment	% Ratio
Antenna 1		
length segment 1 (% CL)	black pigment	8.0%
length segment 2 (%CL)	black pigment	11.3%
length segment 3 (% CL)		14.2%
length segment 4 (% CL)		3.3%
length segment 5 (%CL)		1.5%
total length		38.3%
a-seta (% CL)		13.0%
b-seta (% CL)	few spinules pointing bas	42.9%
c-seta (% CL)		12.3%
d-seta (% CL)		45.2%
e-seta (% CL)	spinules pointing distally	54.2%
dorsal seta		3.9%
Antenna 2		
protopodite (% CL)		47.4%
exopodite 1 (% CL)		21.7%
exopodite 2 -9 (% exopodite 1)		44.4%
longest swimming seta (% CL)	long hairs	41.9%
mid-length swimming seta (% CL)	bare	8.9%
shortest swimming seta (% CL)	bare	2.7%
endopodite segment 1 (% CL)		9.6%
a-seta (%CL)	bare	3.8%
b-seta (%CL)	hairs	9.6%
endopodite segment 2 (% CL)		3.0%
f-seta (% CL)		39.8%
g-seta (% CL)		43.1%
right clasper shank length (%CL)		10.2%
left clasper shank length (%CL)		9.8%
h-seta (% CL)		7.2%
i-seta (% CL)		19.9%
j-seta (% CL)		11.4%

Table 4.8. Measurements of male *Huxleyoecia muscatensis* (n = 1, %CL = Carapace Length).

	Number / Comment	% Ratio
Mandible		
basale		
endopodite segment 1 dorsal setae	1 plumose	
endopodite segment 1 ventral setae	4	
endopodite segment 2 dorsal setae	3	
endopodite segment 2 ventral setae	2	
endopodite segment 3 terminal setae	7	
endopodite segment 3 longest claw (% CL)		20.8%
endopodite segment 3 longest claw (% limb)		83.1%
teeth on basal endite	2 + 6	
pars incisiva	10	
distal tooth list	13 + 2	
proximal list	1 + 2 + 1 + 12	
setae laterally on endite	2 + 2	
exopodite	1 plumose	
limb length (%CL)		25%
Maxilla		
basal segment anterior setae	6	
basal segment lateral setae	1	
basal segment posterior setae	3	
terminal spines	0	
distal segment claw setae	2	
distal segment normal setae	3	

Table 4.9. Measurements of male *Huxleyoecia muscatensis* (n = 1, %CL = Carapace Length).

	Number / Comment	Length mm / % Ratio
Fifth limb		
basale ventral setae	3 + 2 + 1 plumose	
basale lateral setae	3 + 1 plumose	
basale dorsal setae	1 long	
endopodite segment 1 ventral setae	2	
endopodite segment 1 dorsal setae	1	
height		0.043
length		0.138
height/length %		30.9%
endopodite terminal setae		0.155
		0.110
		0.065
longest terminal seta (% CL)		9.3%
length of segment 2		0.028
longest seta/length segment 2		563.6%
length of limb		0.228
longest seta/length limb		68.1%

Table 4.10. Measurements of male *Huxleyoecia muscatensis* (n = 1, %CL = Carapace Length).

	Number / Comment	Length mm / % Ratio
Sixth limb		
basale ventral setae	2 + 1 + 2 all plumose	
basale lateral setae	3 plumose	
basale dorsal setae	1 plumose	
endopodite segment 1 ventral setae	1	
endopodite segment 1 dorsal setae	0	
endopodite segment 2 ventral setae	1	
endopodite segment 2 dorsal setae	1	
height		0.050
length		0.210
segment 2 height/length %		23.8%
endopodite segment 3 terminal setae		0.863
		0.863
		0.863
limb length		0.650
longest seta (% CL)		52.0%
longest seta (% segment 2)		410.7%
longest seta (% limb)		132.7%
Caudal furca		
paired claws		0.280
		0.205
		0.175
		0.155
		0.120
		0.095
		0.060
		0.045
longest claw (% CL)		16.9%
Intromittent organ		
length		0.470
length (% CL)		28.3%
maximum width		0.055

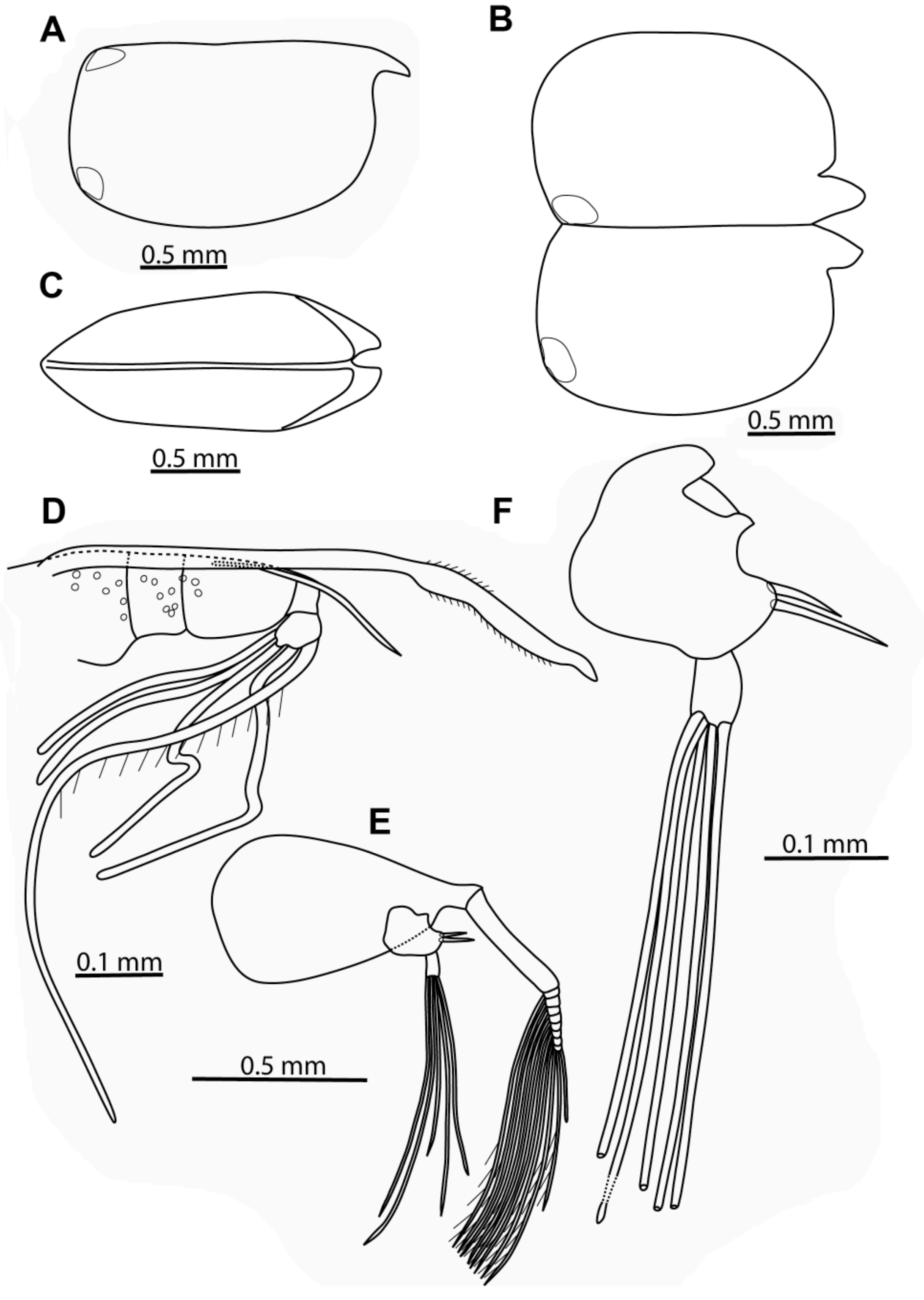


Figure 4.1. *H. muscatensis* gen.et sp.nov. female (A) lateral view, (B) carapace dissected and viewed dorsally, (C) ventral view, (D) first antenna and frontal organ, (E) second antenna, (F) endopodite.

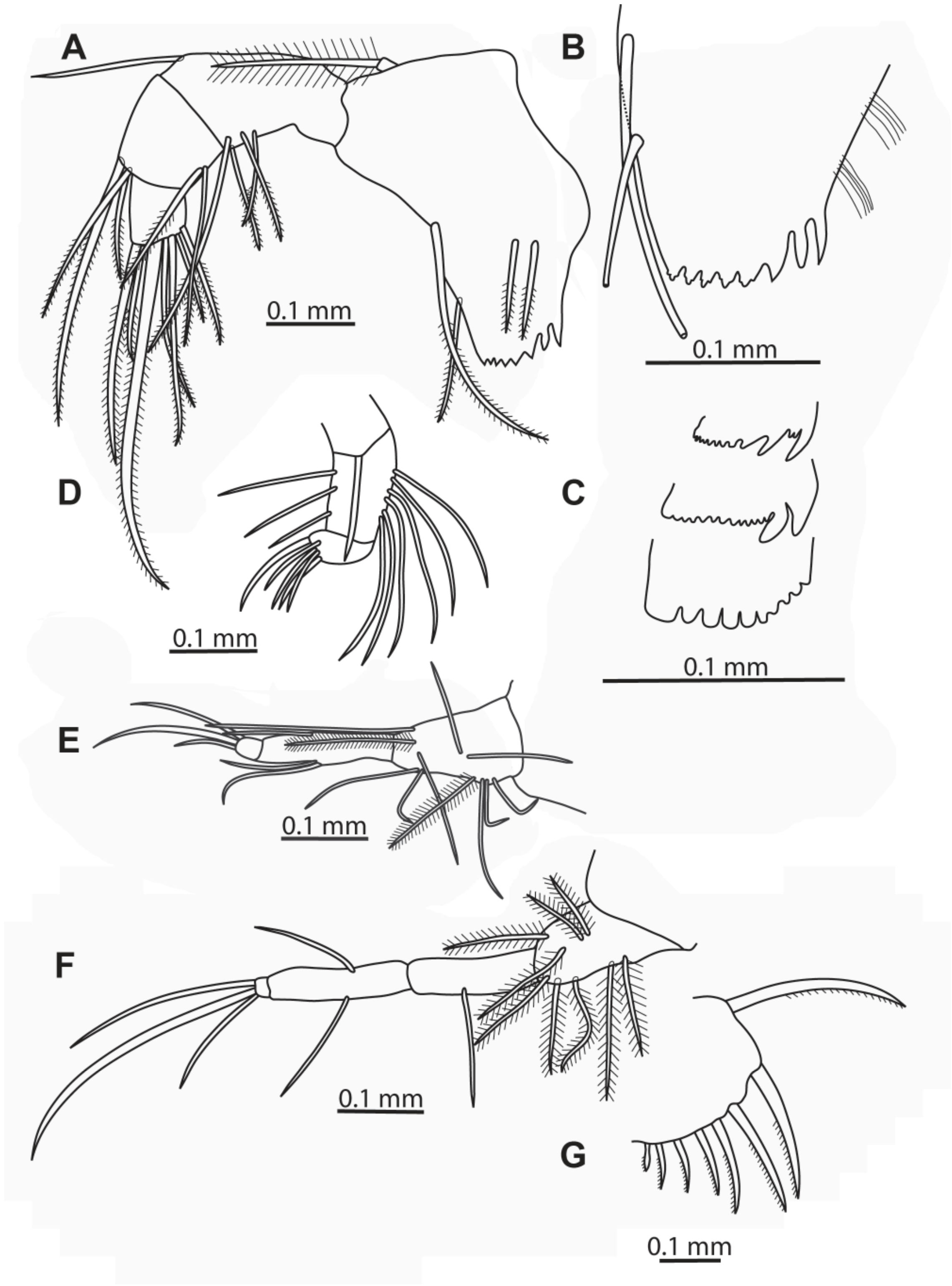


Figure 4.2. *H. muscatensis* gen.et sp.nov. female (A) mandible, (B) basal endite of mandible, (C) tooth lists, (D) maxilla, (E) fifth limb, (F) sixth limb, (G) caudal furca.

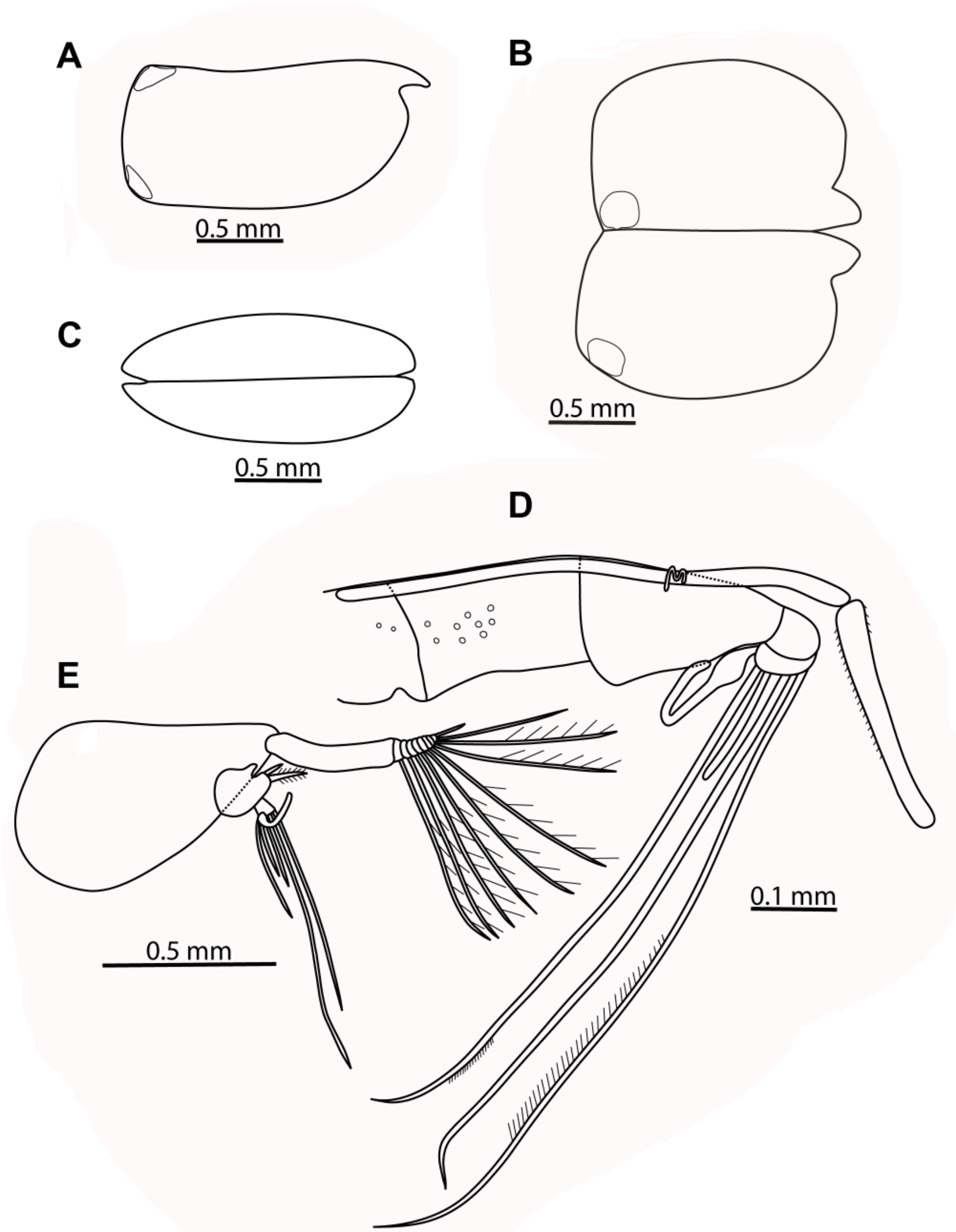


Figure 4.3. *H. muscatensis* gen.et sp.nov. male (A) lateral view, (B) carapace dissected and viewed dorsally, (C) ventral view, (D) first antenna and frontal organ, (E) second antenna.

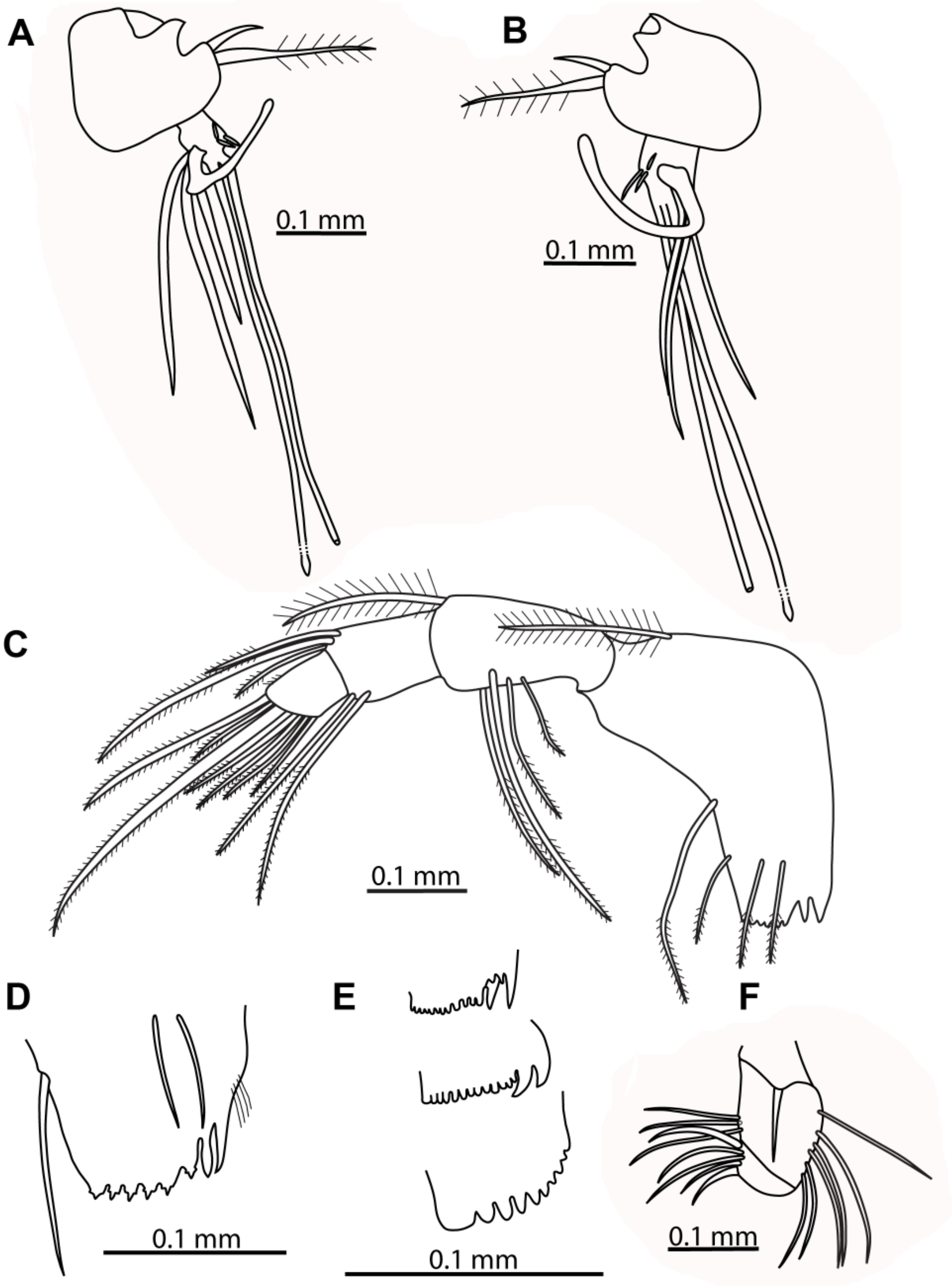


Figure 4.4. *H. muscatensis* gen.et sp.nov. male (A) left endopodite, (B) right endopodite, (C) mandible, (D) basal endite of mandible, (E) tooth lists, (F) maxilla.

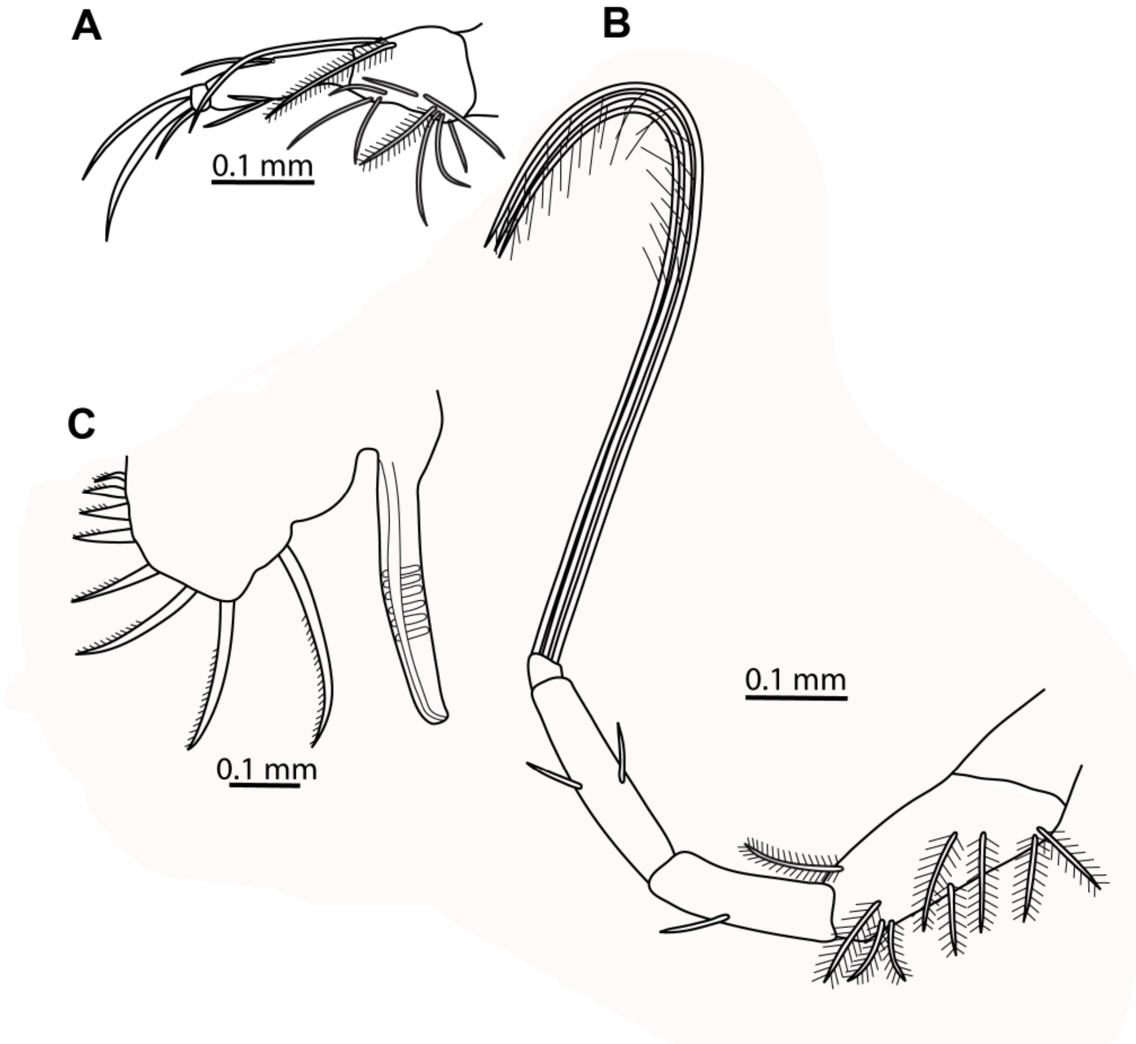


Figure 4.5. *H. muscatensis* gen.et sp.nov. male (A) fifth limb, (B) sixth limb, (C) caudal furca and intromittent organ.

4.9 References

Angel MV. Blachowiak-Samolyk K. 2006. *Obtusoecia* (Halocyprida: Myodocopa: Ostracoda) a bipolar planktonic oceanic genus: taxonomy, bathymetry and zoogeographical distribution. Annales Zoologici (Warszawa), 2006, 56 (1): 1–48.

Angel MV. Blachowiak-Samolyk K. Drapun I., Castillo R. 2007. Changes in the composition of planktonic ostracod populations across a range of latitudes in the North-east Atlantic. Progress in Oceanography, 73, 1, 60-78.

Roe HSJ. Shale DM. 1979. A new multiple rectangular midwater trawl (RMT1+8) and some modifications to the Institute of Oceanographic Sciences' RMT1+8. Marine Biology, 50, 283–288.

Roe HSJ. Baker AdeC. Carson RM. Wild RA. Shale DM. 1980. Behaviour of the Institute of Oceanographic Sciences' rectangular midwater trawls; theoretical aspects and experimental observations. Marine Biology, 56, 247-259.

Skogsberg T. 1920. Studies on marine ostracods. Part 1. (Cypridinids, halocyprids and polycopids). Zoologiska Bidrag Fran Uppsala, Supplement 1, 1–784.

Chapter 5

Description of a new genus *Mollicoecia* (Halocyprididae, Ostracoda) and a redescription of *Mollicoecia minki* from the Gulf of Oman.

5.1 Abstract

During the northeast monsoon of 1997, plankton samples were collected from the Gulf of Oman at 24° N, 58° E (*Discovery* Station 54001), using the multiple rectangular midwater trawl (RMT1 +8) net system. A day and night series of bathymetrically stratified plankton samples was taken to a depth of 2000 m. Ostracods were sorted from the RMT1 samples and analysed. At 2000 m a species of the genus of the previously described genus *Mollicia* Poulsen, 1973 was identified. However, Marples, (1964) had already used the name *Mollicia* for a genus of jumping spider. This name is preoccupied so a replacement name, *Mollicoecia*, is given to this genus of halocyprid ostracod and includes the following species *M. mollis (*Müller, 1906), *M. kampta* (Müller, 1906), *M. acanthosphora* (Müller, 1906), *M. amblypostha* (Müller, 1906), *M. tyloda* (Müller, 1906) and *M. minki (*Poulsen, 1973). The latter species is redescribed herein.

5.2 Introduction

The influence of upwelling on biological processes in the Gulf of Oman was investigated during the northeast monsoon of 1997. A series of day and night bathymetrically stratified horizontal tows was carried out from the RRS *Charles Darwin.* The multiple rectangular midwater trawl (RMT1+8) system (Roe and Shale 1979, Roe et al. 1980) was used at oceanic station *Discovery* 54001 (24° 12'N, 58° 40'E) to a depth of 2000 m. From the RMT1 (mesh size o.33 mm) plankton samples of halocyprid ostracods were sorted and analysed for species composition. These crustaceans are small and ubiquitous in marine mesozooplankton communities, feeding on detritus sinking from the surface into the deep ocean (Angel et al. 2007).

At a depth of 2000 m a species of the previously described genus *Mollicia* (Poulsen, 1973) was identified. However, the name *Mollicia* was preoccupied for a genus of jumping spider *Mollicia* (Marples, 1964), so a replacement name is required. *Mollicoecia* is proposed here as the replacement name for this genus of halocyprid ostracod and it includes the following species *M. mollis* (Müller, 1906), *M. kampta* (Müller, 1906), *M. acanthosphora* (Müller, 1906), *M. amblypostha* (Müller, 1906), *M. tyloda* (Müller, 1906) and *M. minki* (Poulsen, 1973). *Mollicoecia minki*, new combination, is given a modern comprehensive description herein.

5.3 Materials and Methods

The zooplankton samples collected in the Gulf of Oman, during the northeast monsoon at Station 54001, were first fixed in 5 % seawater formalin. After 24 h the samples were removed from the formalin and preserved in Steadman’s preserving fluid (0.5 % propylene phenoxetol, 4.5 % propylene glycol, 5 % formalin seawater solution). The material was stored from 1997 until 2006 at the National Oceanography Centre, Southampton. In 2006 the zooplankton samples were moved to the Natural History Museum, London for analysis. The Steadman's preserving fluid was replaced by 80 % industrial methylated ethanol and the planktonic ostracods were picked out and sorted to species.

One exemplar female and one exemplar male were selected and carapace measurements of length, breadth and height were recorded. Each specimen was dissected on a cavity slide in lactophenol containing lignin pink using a stereo-microscope. The carapace, antennae and limbs were mounted in lactophenol and examined under an Olympus BH2 compound microscope using differential interference contrast. A standard set of measurements of the antennae, limbs and setae (Angel and Blachowiak-Samolyk 2006) were made and morphological characteristics were recorded. The measurements were standardised by defining them as a percentage of the carapace length. Drawings were made of the complete animal and the individual dissected parts using a camera lucida. These outlines were scanned, re-drawn using Adobe Illustrator and collated as plates in Adobe Photoshop. The nomenclature used by Skogsberg (1920) for the structure and setation from the antenna, mandible, maxilla, 5th limb, 6th limb, and caudal furca has been used throughout.

5.4 Systematics

Class **OSTRACODA** Latreille, 1802

Subclass **MYODOCOPA** Sars, 1866

Order **HALOCYPRIDA** Dana, 1853

Suborder **HALOCYPRIDINA** Dana, 1853

Family **HALOCYPRIDIDAE** Dana, 1853

Subfamily **CONCHOECIINAE** Claus, 1891

Genus ***Mollicoecia*** Graves gen. nov.

Conchoecia (pr.prt.) Dana, 1852: S.52; S. 1298; *Conchoecia* Claus, 1874, S.6; *Conchoecia* Sars, 1887 S 66,86; *Conchoecia* Müller, 1894, S. 226; *Conchoecinae* Claus, 1890, S 6; 1891, S 55, *Conchoecia* Müller, 1906, 106 – 115, *Conchoecia* Müller, 1912, 85- 87, *Conchoecia* Granata and Caporiacco, 1949, 23 - 31, *Conchoecia* Deevey, 1968, 99 -103

Mollicia Poulsen, 1973: 151-165

5.5 Diagnosis of *Mollicoecia* replacement name

Carapace lacking in sculpture; rostra well developed, equal in length; antero-ventral margin curving. Right valve asymmetrical gland opening at posterior ventral corner; left valve asymmetrical gland opening at posterior dorsal corner. Frontal organ sexually dimorphic: female with long stem and curving capitulum with pointed tip, spinules present along dorsal and ventral edge; male short stem with straight capitulum clearly sutured with stem; spinules along both dorsal and ventral edges. Armature of female first antenna, e-seta with spinules and sword-shaped tip; male b-seta with narrow pad and double row of approximately nine pairs of spinules pointing distally; d-seta with spinules pointing distally; e-seta with large number of spinules pointing basally and sword-shaped tip. Female second antenna lacking c-, d- or e-setae; endopodite f- and g-setae distally sword-shaped; h-, i- ,j-setae end with number of small spinules; male right "hook" long and evenly curved; left "hook" short and angled f-and g-setae with few spinules along length. Mandible with dorsal seta on first segment in female bare; plumose in male; longest claw in males approximately one fifth carapace length. Maxilla basal segment bearing six bare anterior setae and three posterior setae, distal segment bearing two claw setae and three normal setae. Sixth limb sexually dimorphic; terminal segment of male with three long subequal setae with fine hairs distally.

Etymology The genus name, *Mollicoecia*, is similar to the previous name of *Mollicia* Poulsen, 1973, that is preoccupied, and *–oecia* the standard ending for the majority of genera of the subfamily Conchoeciinae. Species name *minki* given by Poulsen 1973.

5.6 *Mollicoecia minki,* new combination

(Figures 5.1 – 5.5)

Mollicia minki Poulsen, 1973: 164-165 Fig. 83

Material

Permanent preparations of the dissected material are deposited in the collections of the Natural History Museum, London registration number NHMUK 2011.8021 for the exemplar female on six slides and NHMUK 2011.8022 for the exemplar male on nine slides. The remaining two females and four males are retained in 80% industrial methylated ethanol registration numbers NHMUK 2011.8023 - 8028

Description Morphological characters of the carapaces and internal structures are summarised in Tables 5.1 to 5.10.

Female

Carapace (Figures 5.1 A, B, C) Mean length 3.31 ± 0.05 mm (n = 3). Carapace of exemplar specimen (Table 5.1) length 3.36 mm; height 1.60 m; breadth 1.40 mm. Height:length ratio 47.6 %CL, breadth:length ratio 41.7 %CL. In lateral view carapace slightly sculptured. Carapace maximum height just posterior to mid-length. Ventral margin curving smoothly into posterior margin. Opening of asymmetrical gland at posterior ventral corner of right valve; left valve asymmetrical gland opening at posterior dorsal corner.

Frontal organ (Table 5.1; Figure 5.1 D) Frontal organ stem slender, almost straight and longer than first antenna. Capitulum curving ventrally with pointed end: small number of spinules along dorsal edge; small spinules along ventral edge. Total length 34.4 %CL, much longer than first antenna.

First antenna (Table 5.2; Figure 5.1 D) Five-segmented. Limb length 24.9 %CL. Segments 1 and 2 with visible spots of black pigment; small spinules along ventral edge; third segment with dorsal seta with hairs 15.8 %CL. Fifth segment with five unequal setae; a-seta 7.1 %CL; b-seta 13.8 %CL; c-seta 10.9 %CL; d-seta 15.8 %CL; e-seta 39.4 %CL with spinules pointing distally and sword-shaped tip.

Second antenna (Table 5.2; Figure 5.1 E) Protopodite 40.6 %CL. First exopodite segment about half length of protopodite; small hook on second exopodite segment. Most swimming setae three quarters length of protopodite, all but shortest seta with long hairs distally. Endopodite first segment (Figure 5.1 F) with short, pointed a-seta; b-seta pointed and bare; second segment lacking c-, d- or e-setae; f-seta 25.3 %CL widened distally and spinules along length; g-seta widened distally with spinules along length 37.2 %CL; h-seta 9.5 %CL; i-seta 21.6 %CL; j-seta 14.9 %CL all with spinules basally.

Mandible (Table 5.3; Figures 5.2 A) Coxale toothed edge of pars incisiva with ten large blunt teeth. Distal tooth list with two large and approximately fourteen small pointed teeth (Figure 2 C). Proximal tooth list slightly narrower, with one large tooth and approximately twelve small pointed teeth. Outer margin of toothed edge of basal endite (Figure 2 B) with two large dagger-shaped teeth, second with rounded tip, and six subserrate teeth. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with bare dorsal seta and four finely spinose ventral setae. Second segment with two ventral and three dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla (Table 5.3; Figure 5.2 D) Basal segment with six anterior, one lateral and three posterior setae. Distal segment comparatively short and wide with five bare terminal claw setae.

Fifth limb (Table 5.4; Figure 5.2 E) Ventrally basale with one plumose and six bare setae, laterally one plumose and two bare setae, dorsally single long seta – remnant of exopodite. First endopodite segment with two ventral setae and one dorsal seta, all bare. Second segment with three unequal, curved terminal claw setae; middle claw longest 7.1 %CL.

Sixth limb. (Table 5.5; Figure 5.2 F) Basale with five plumose ventral setae, laterally one plumose setae and one short, bare seta dorsally. First endopodite segment with one ventral spinose seta. Second segment with one spinose seta ventrally and one dorsally. Third segment with three unequal spinose, terminal claw setae; middle claw longest 11.8 %CL.

Caudal furca (Table 5.4) First pair claw setae, 16.0 %CL; paired setae 2 – 8 missing.

Male

Carapace (Figures 5.3 A, B, C) Mean length 2.98 ± 0.02 mm (n = 5). Carapace of exemplar specimen (Table 5.6) length 3.00 mm; height 1.52 mm; breadth 1.20 mm. Height:length ratio 50.7 %CL, breadth:length ratio 40.0 %CL. In lateral view carapace unsculptured as in female, maximum height just anterior to mid-length. Ventral margin curving smoothly into posterior margin. Opening of asymmetrical gland at posterior ventral corner of right valve; left valve asymmetrical gland opening at posterior dorsal corner.

Frontal organ (Table 5.6; Figure 5.3 D) Frontal organ stem straight; shorter than first antenna. Capitulum long, with slightly pointed distal end. Dorsal and ventral surface with spinules proximally. Total length 39.2 %CL, much longer than first antenna.

First antenna (Table 5.7; Figure 5.3 D) With five segments. Limb length 37.2 %CL. Black pigmented spots visible in segments 2 and 3; on third segment dorsal seta bare 3.3 %CL. Fifth segment with five unequal setae; a-seta with proximal bulge16.0 %CL; b-seta 42.0 %CL; small pad with few spinules pointing distally; c-seta 13.3 %CL; d-seta 39.7 %CL with spinules pointing distally; e-seta 48.3 %CL with spinules pointing basally and sword-shaped tip.

Second antenna (Table 5.7; Figure 5.3 E) Protopodite 45.0 %CL. Length of first exopodite segment about half length of protopodite; small hook on second exopodite segment. All swimming setae shorter than protopodite, all but shortest seta with long hairs distally. Endopodite first segment with short, pointed, bare a-seta; long b-seta pointed with hairs; c-, d-, and e-setae all very short; f-seta with spinules along length and distally sword-shaped 36.3 %CL; g-seta with spinules along length and sword-shaped distally 45.2 %CL; h-seta short 5.4 %CL; i-seta 34.5 %CL; j-seta 23.5 %CL. Right endopodite (Figure 5.4 B) with elongated clasping organ in form of hook; long proximal shank with thumb-shaped peg and small triangular tooth; long curved end piece with papillae at tip 9.8 %CL. Left endopodite (Figure 5.4 A) ‘hook’ much shorter and angled acutely upwards 5.3 %CL.

Mandible (Table 5.8; Figures 5.4 C) Coxale toothed edge of pars incisiva with ten large blunt teeth. Distal tooth list with two large and approximately fourteen small pointed teeth (Figure 5.4 E). Proximal tooth list slightly narrower, with one large tooth and approximately twelve small pointed teeth. Outer margin of toothed edge of basal endite (Figure 5.4 D) with two large dagger-shaped teeth, second with rounded tip, and six subserrate teeth. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with bare dorsal seta and four finely spinose ventral setae. Second segment with two ventral and three dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla and Fifth limb (Tables 5.8, 5.9; Figures 5.4 F, 5.5 A) Structure and arrangement of setae in maxilla and fifth limb as in female.

Sixth limb (Table 5.10; Figure 5.5 B) Basale with six plumose setae ventrally, one lateral plumose seta and one bare dorsal exopodal seta. First endopodite segment with single, ventral seta. Second endopodite segment with one seta ventrally and one dorsally. Third segment with three very long terminal setae, subequal, evenly curved with long hairs, 32.5 %CL.

Caudal furca (Table 5.10; Figure 5.5 C) Structure and arrangement of furcal claws similar to female; longest claw 14.8 %CL.

Intromittent organ (Table 5.10; Figure 5.5 C) Male copulatory appendage long, narrow with rounded tip and six oblique muscles 31.7 %CL.

Remarks

The genus *Mollicia* was created by Poulsen (1973) to accommodate the *Conchoecia mollis* group as defined by Müller (1906). Müller's "*Mollis* group" included *Conchoecia mollis* Müller, 1906, *C. amblypostha* Müller, 1906, *C. kampta*, *C. acanthophora* Müller, 1906, *C. tyloda* Müller, 1906, *C. antipoda* Müller, 1906, *C. distans* Müller, 1906, *C. plactolycos* Müller, 1906, *C. dichotoma* Müller, 1906, *C. rhynchena* Müller, 1906 and *C. cellularis* Müller, 1906. However, Poulsen excluded *C. antipoda* Müller, 1906, *C. distans* Müller, 1906, *C. plactolycos* Müller, 1906, *C. rhynchena* Müller, 1906, *C. dichotoma* Müller, 1906 and *C. cellularis* Müller, 1906 from his new genus on the justification that Müller's original diagnosis of the group was too imprecise. Poulsen's genus therefore included *M. mollis, M. amblypostha, M. kampta, M. acanthophora*, *M. tyloda* and his newly described species *M. minki*.

5.7 Discussion

When Poulsen (1973) designated *Mollicia* as the genus name for the group, he was unaware of the genus, *Mollicia* Marples, 1964 which had been used for a jumping spider. Consequently *Mollicia* Poulsen, 1973 is unavailable as a genus name. Here a new genus of *Mollicoecia* has been erected for Poulsen's group and a new comprehensive description of *M. minki* from the Gulf of Oman has been undertaken to include measurements of the limbs and setae.

5.8 Tables and Figures

Table 5.1. Measurements of female *Mollicoecia minki* (n = 1, %CL = Carapace Length, PDC = posterior dorsal corner, PVC = posterior ventral corner).

	Number / Comment	Length mm / % Ratio
Carapace		
length		3.36
height		1.60
breadth		1.40
height/length %		47.6%
breadth/length %		41.7%
PDC, left tip to posterior hinge (% CL)		5.6%
PDC, right tip to posterior hinge (% CL)		5.6%
rostrum, left tip to anterior hinge (% CL)		11.5%
rostrum, right tip to anterior hinge (% CL)		11.5%
incisure, left rostrum tip to inner edge (% CL)		10.8%
incisure, right rostrum tip to inner edge (% CL)		8.9%
opening of left gland	PDC	
opening of right gland	PVC	
Frontal organ		
capitulum length (% CL)		13.2%
stem length (% CL)		21.2%
total length (% CL)		34.4%
length relative to antenna 1		

Table 5.2. Measurements of female *Mollicoecia minki* (n = 1, %CL = Carapace Length).

	Number / Comment	% Ratio
Antenna 1		
length segment 1 (% CL)	small spines	11.9%
length segment 2 (% CL)	small spines	3.7%
length segment 3 (% CL)		4.6%
length segment 4 (% CL)		3.1%
length segment 5 (% CL)		1.5%
total length (% CL)		24.9%
a-seta (% CL)		7.1%
b-seta (% CL)		13.8%
c-seta (% CL)		10.9%
d-seta (% CL)		15.8%
e-seta (% CL)	spines pointing distally	39.4%
dorsal seta	hairs	15.9%
Antenna 2		
protopodite (% CL)		40.6%
exopodite 1 (% CL)		18.2%
exopodite 2 -9 (% exopodite 1)	hook on 2nd exopoodite	35.1%
longest swimming seta (% CL)		30.9%
mid-length swimming seta (% CL)		
shortest swimming seta (% CL)		3.1%
endopodite segment 1 (% CL)		8.5%
a-seta		1.9%
b-seta		2.8%
endopodite segment 2 (% CL)		2.2%
f-seta (% CL)	small spines	25.3%
g-seta (% CL)	small spines	37.2%
h-seta (% CL)	small spines	9.5%
i-seta (% CL)	small spines	21.6%
j-seta (% CL)	small spines	14.9%

Table 5.3. Measurements of female *Mollicoecia minki* (n = 1, %CL = Carapace Length).

	Number / Comment	% Ratio
Mandible		
basale		
endopodite segment 1 dorsal setae	1 bare	
endopodite segment 1 ventral setae	4	
endopodite segment 2 dorsal setae	3	
endopodite segment 2 ventral setae	2	
endopodite segment 3 terminal setae	7	
endopodite segment 3 longest claw (% CL)		16.7%
endopodite segment 3 longest claw (% limb)		53.6%
teeth on basal endite	2 + 6	
pars incisiva	10	
distal tooth list	2 + 14	
proximal list	1 + 12	
setae laterally on endite	2 + 2	
exopodite	1 plumose	
limb length (%CL)		31.3%
Maxilla		
basal segment anterior setae	6	
basal segment lateral setae	1	
basal segment posterior setae	3	
terminal spines	3	
distal segment claw setae	2	
distal segment normal setae	3	

Table 5.4. Measurements of female *Mollicoecia minki* (n = 1, %CL = Carapace Length).

	Number / Comment	Length mm / % Ratio
Fifth limb		
basale ventral setae	3 + 3 + 1 plumose	
basale lateral setae	2 + 1 plumose	
basale dorsal setae	1 long	
endopodite segment 1 ventral setae	2	
endopodite segment 1 dorsal setae	1	
height		0.07
length		0.25
height/length %		28.6%
endopodite terminal setae		0.23
		0.24
		0.15
longest terminal seta % CL		7.1%
length of segment 2		0.21
longest seta/length segment 2		114.3%
length of limb		0.49
longests seta/ length limb		49.0%

Table 5.5. Measurements of female *Mollicoecia minki* (n = 1, %CL = Carapace Length).

	Number / Comment	Length mm / % Ratio
Sixth limb		
basale ventral setae	5 plumose	
basale lateral setae	1 plumose	
basale dorsal setae	1short bare	
endopodite segment 1 ventral setae	1	
endopodite segment 1 dorsal setae	0	
endopodite segment 2 ventral setae	1	
endopodite segment 2 dorsal setae	1	
height		0.06
length		0.21
segment 2 height /length %		28.6%
endopodite segment 3 terminal setae		0.40
		0.37
		0.25
limb length		0.91
longest seta % CL		11.8%
longest seta % segment 2		188.1%
longest seta % limb		43.3%
Caudal furca		
paired claws		0.54
		n.d.
		n.d.
		n.d.
		n.d.
		n.d.
		n.d.
		n.d.
longest claw % CL		16.0%

Table 5.6. Measurements of male *Mollicoecia minki* (n = 1, %CL = Carapace Length, PDC = posterior dorsal corner, PVC = posterior ventral corner).

	Number / Comment	Length mm / % Ratio
Carapace		
length		3.00
height		1.52
breadth		1.20
height/length %		50.7%
breadth/length %		40.0%
PDC, left tip to posterior hinge (% CL)		5.5%
PDC, right tip to posterior hinge (% CL)		5.5%
rostrum, left tip to anterior hinge (% CL)		11.7%
rostrum, right tip to anterior hinge (% CL)		11.7%
incisure, left rostrum tip to inner edge(% CL)		12.5%
incisure, right rostrum tip to inner edge (% CL)		11.5%
opening of left gland	PDC	
opening of right gland	PVC	
Frontal organ		
capitulum length (% CL)		17.3%
stem length (% CL)		21.8%
total length (% CL)		39.2%
length relative to antenna 1	longer	

Table 5.7. Measurements of male *Mollicoecia minki* (n = 1, %CL = Carapace Length).

	Number / Comment	% Ratio
Antenna 1		
length segment 1 (% CL)		9.7%
length segment 2 (% CL)		9.7%
length segment 3 (% CL)		13.5%
length segment 4 (% CL)		3.0%
length segment 5 (%CL)		1.3%
total length		37.2%
a-seta (% CL)		16.0%
b-seta (% CL)		42.0%
c-seta (% CL)		13.3%
d-seta (% CL)		39.7%
e-seta (% CL)		48.3%
dorsal seta		3.3%
Antenna 2		
protopodite (% CL)		45.0%
exopodite 1 (% CL)		19.0%
exopodite 2 -9 (% exopodite 1)		36.8%
longest swimming seta (% CL)		37.9%
mid-length swimming seta (% CL)		4.6%
shortest swimming seta (% CL)		3.0%
endopodite segment 1 (% CL)		8.2%
a-seta (%CL)		2.4%
b-seta (%CL)		3.7%
endopodite segment 2 (% CL)		2.0%
f-seta (% CL)		36.3%
g-seta (% CL)		45.2%
right clasper shank length (%CL)		9.8%
left clasper shank length (%CL)		5.3%
h-seta (% CL)		5.4%
i-seta (% CL)		34.5%
j-seta (% CL)		23.5%

Table 5.8. Measurements of male *Mollicoecia minki* (n = 1, %CL = Carapace Length).

	Number / Comment	% Ratio
Mandible		
basale		
endopodite segment 1 dorsal setae	1 plumose	
endopodite segment 1 ventral setae	4	
endopodite segment 2 dorsal setae	3	
endopodite segment 2 ventral setae	2	
endopodite segment 3 terminal setae	7	
endopodite segment 3 longest claw (% CL)		19.0%
endopodite segment 3 longest claw (% limb)		78.6%
teeth on basal endite	2 + 6	
pars incisiva	10	
distal tooth list	14 + 2	
proximal list	12 + 1	
setae laterally on endite	2 + 2	
exopodite	1 plumose	
limb length (%CL)		24.2%
Maxilla		
basal segment anterior setae	6	
basal segment lateral setae	1	
basal segment posterior setae	3	
terminal spines	0	
distal segment claw setae	2	
distal segment normal setae	3	

Table 5.9. Measurements of male *Mollicoecia minki* (n = 1, %CL = Carapace Length).

	Number / Comment	Length mm / % Ratio
Fifth limb		
basale ventral setae	3 + 3 + 1 plumose	
basale lateral setae	2 + 1plumose	
basale dorsal setae	1 long	
endopodite segment 1 ventral setae	2	
endopodite segment 1 dorsal setae	1	
height		0.07
length		0.26
height/length %		26.9%
endopodite terminal setae		0.14
		0.26
		0.23
longest terminal seta (% CL)		8.5%
length of segment 2		0.27
longest seta/length segment 2		94.4%
length of limb		0.49
longest seta/length limb		52.6%

Table 5.10. Measurements of male *Mollicoecia minki* (n = 1, %CL = Carapace Length).

	Number / Comment	Length mm / % Ratio
Sixth limb		
basale ventral setae	6 all plumose	
basale lateral setae	1 plumose	
basale dorsal setae	1 long	
endopodite segment 1 ventral setae	1	
endopodite segment 1 dorsal setae	0	
endopodite segment 2 ventral setae	1	
endopodite segment 2 dorsal setae	1	
height		0.06
length		0.31
segment 2 height/length %		19.4%
endopodite segment 3 terminal setae		0.98
		0.98
		0.98
limb length		1.01
longest seta (% CL)		32.5%
longest seta (% segment 2)		314.5%
longest seta (% limb)		96.3%
Caudal furca		
paired claws		0.45
		0.39
		0.24
		0.18
		0.15
		0.09
		0.08
		0.06
longest claw (% CL)		14.8%
Intromittent organ		
length	six oblique muscles	0.95
length (% CL)		31.7%
maximum width		0.14

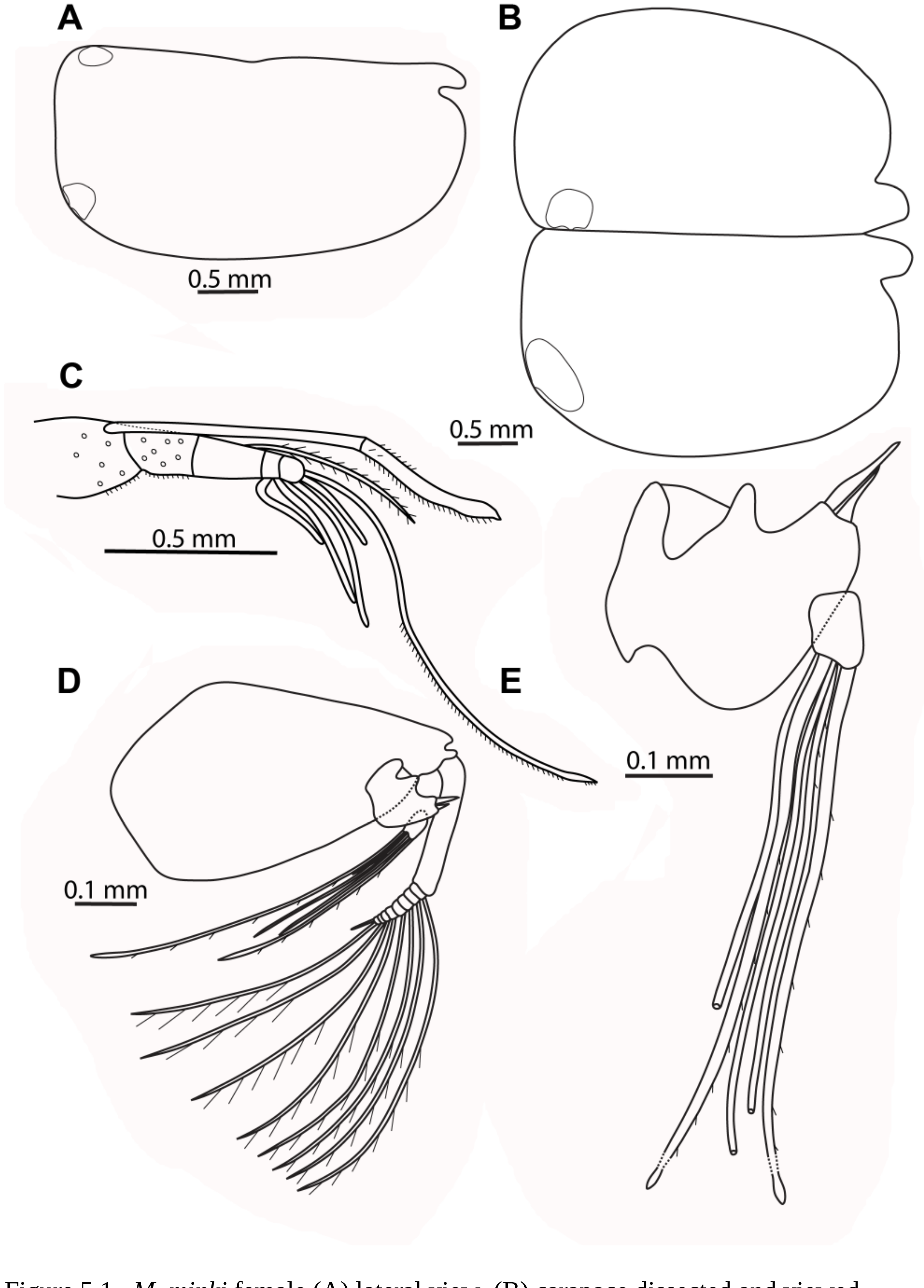


Figure 5.1. *M. minki* female (A) lateral view, (B) carapace dissected and viewed dorsally, (C) first antenna and frontal organ, (D) second antenna, (E) endopodite.

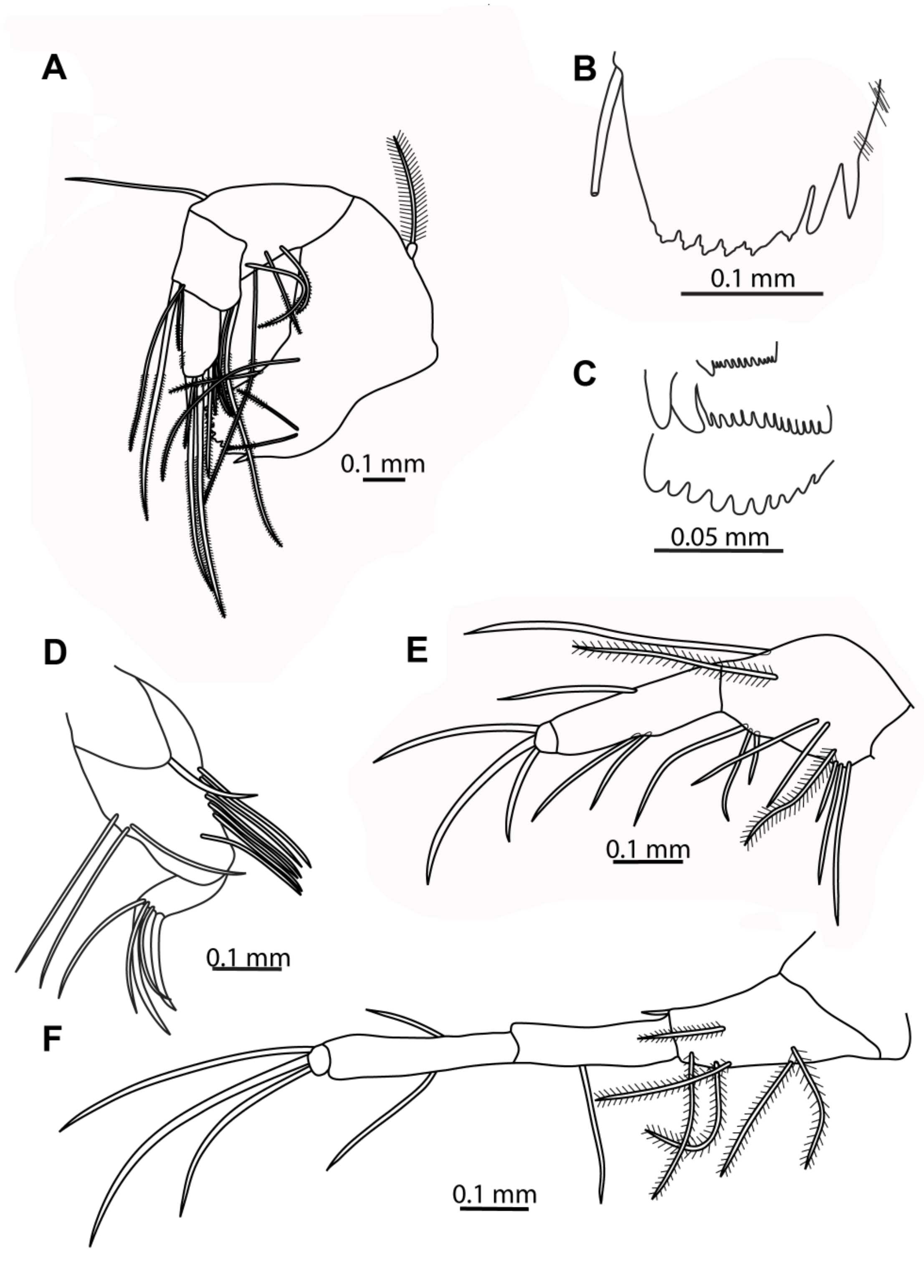


Figure 5.2. *M. minki* female (A) mandible, (B) basal endite of mandible, (C) tooth lists, (D) maxilla, (E) fifth limb, (F) sixth limb.

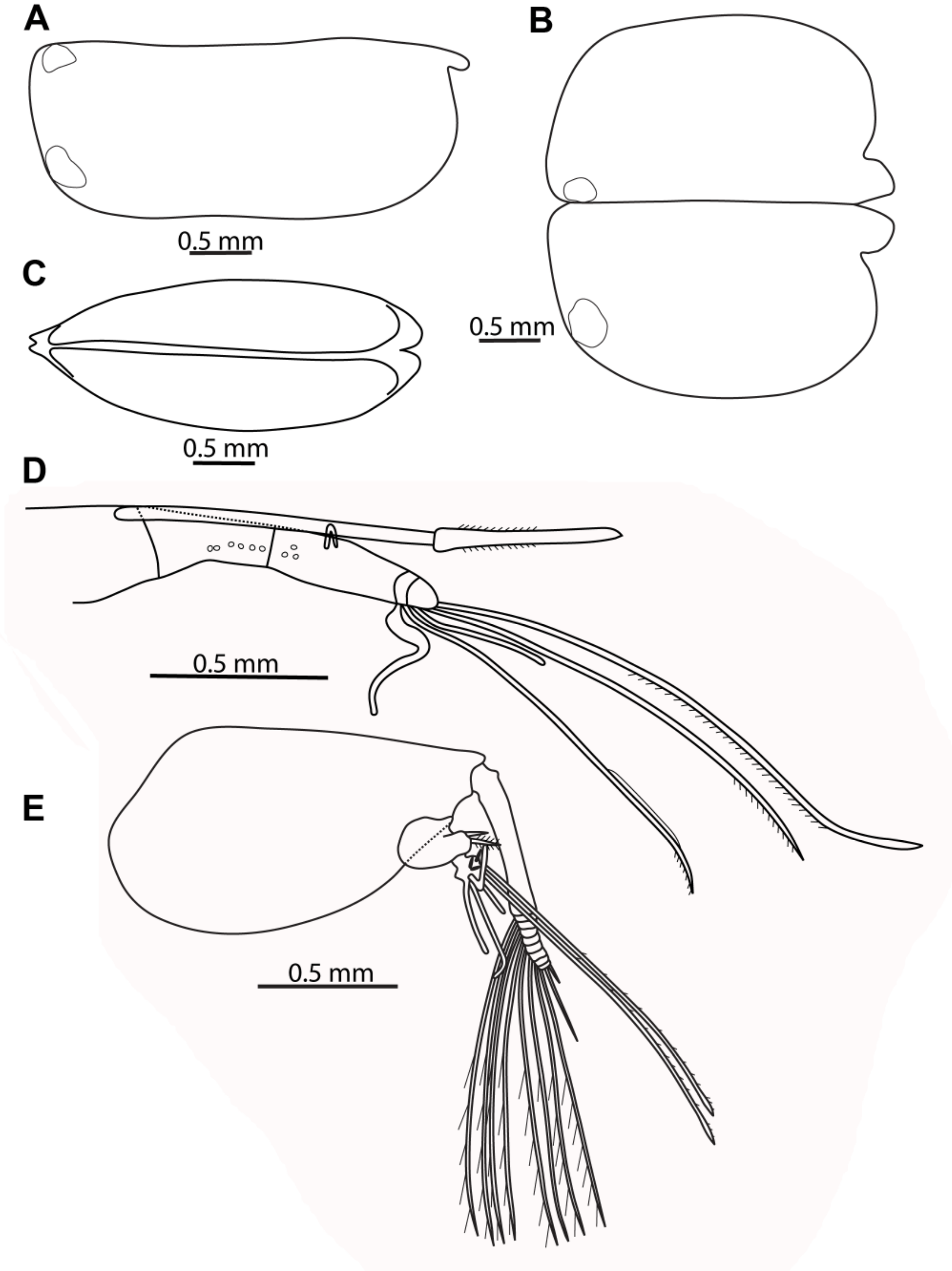


Figure 5.3. *M. minki* male (A) lateral view, (B) carapace dissected and viewed dorsally, (C) ventral view,(D) first antenna and frontal organ, (E) second antenna.

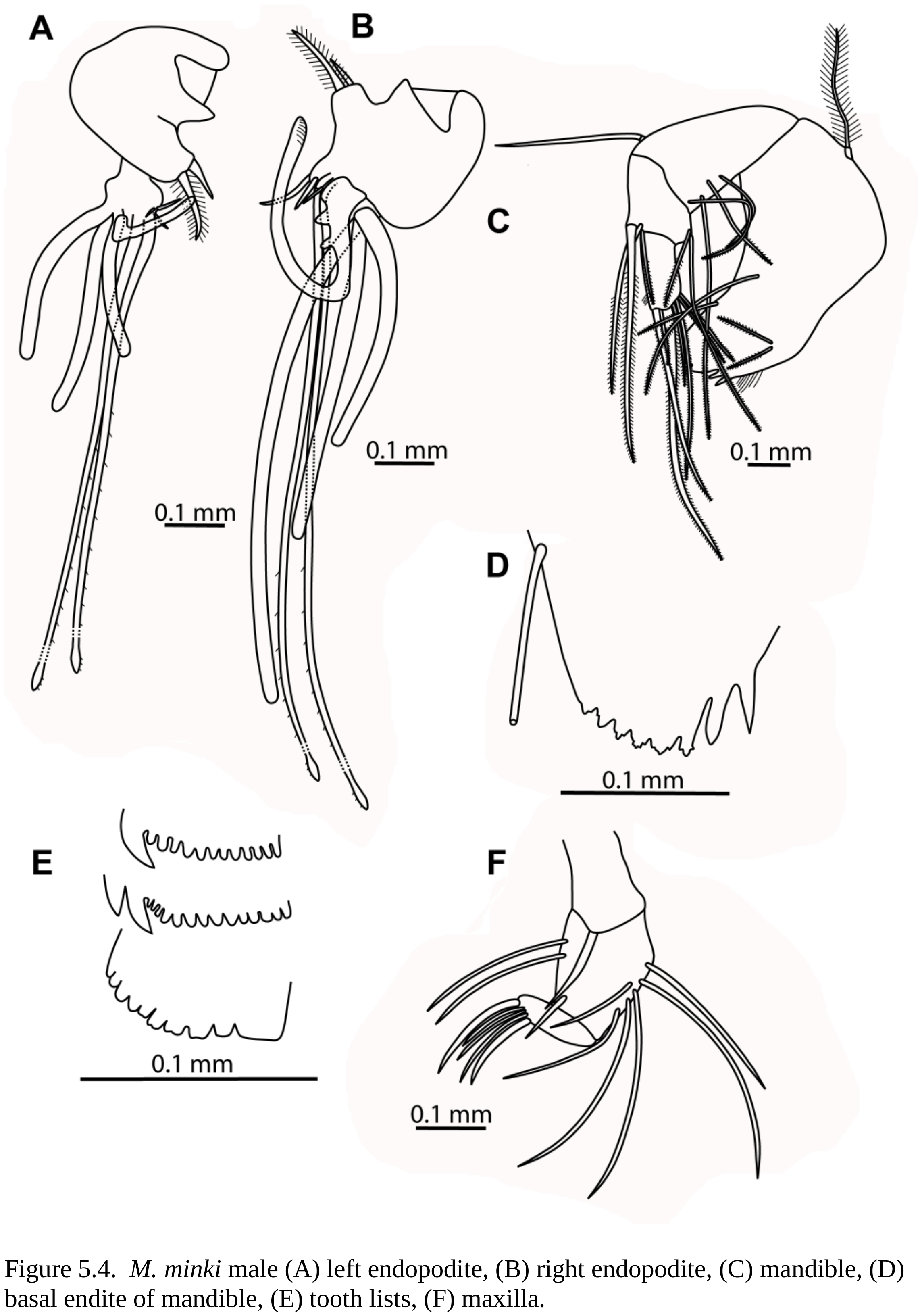


Figure 5.4. *M. minki* male (A) left endopodite, (B) right endopodite, (C) mandible, (D) basal endite of mandible, (E) tooth lists, (F) maxilla.

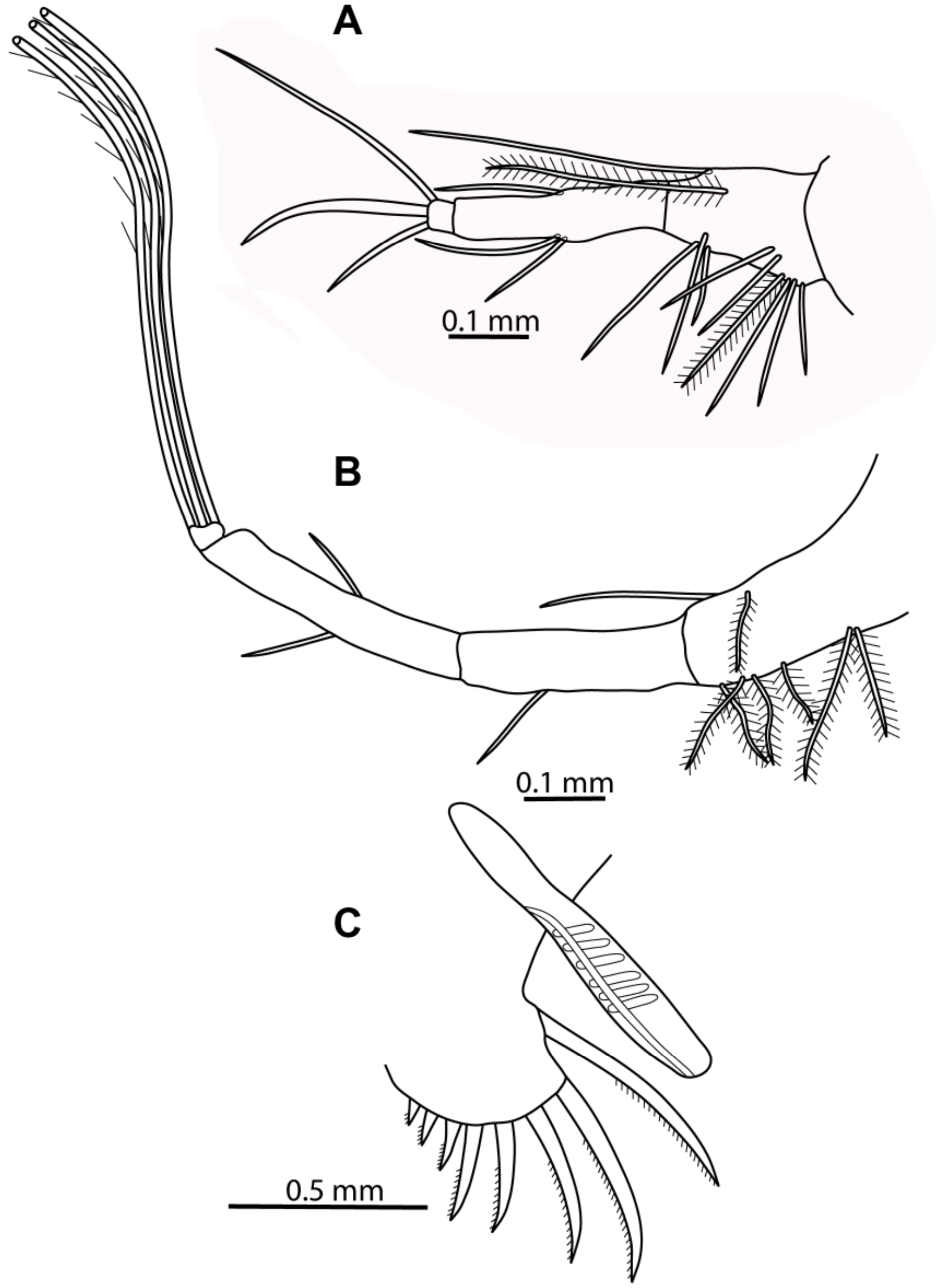


Figure 5.5. *M. minki* male (A) fifth limb, (B) sixth limb, (C) caudal furca and intromittent organ.

5.9 References

Angel MV. Blachowiak-Samolyk K. 2006. *Obtusoecia* (Halocyprida: Myodocopa: Ostracoda) a bipolar planktonic oceanic genus: taxonomy, bathymetry and zoogeographical distribution. Annales Zoologici (Warszawa), 2006, 56 (1): 1–48.

Angel MV. Blachowiak-Samolyk K. Drapun I. Castillo R. 2007. Changes in the composition of planktonic ostracod populations across a range of latitudes in the North-east Atlantic. Progress in Oceanography, 73, 1, 60-78.

Claus C. 1874. Die Familie der Halocypriden. Schriften zoologischen Inhalts, 1, 4-16.

Claus C. 1890. Die Gattungen und Arten der mediterranen und atlantischen Halocypriden nebst Bemerkungen über die Organisation derselben. Arb. Zool. Inst. Univ. Wien, 9, 1-34.

Claus C. 1891. Die Halocypriden des Atlantischen Oceans und Mittelmeeres. Alfred Hölder, Wien, 1-81.

Dana J.D. 1852. Crustacea. Part II. In: United States Exploring Expedition During the Years 1838, 1839, 1840, 1841, 1842 Under the Command of Charles Wilkes, U.S.N., 13, (2), 689-1618.

Deevey G.B. 1968. Pelagic ostracods of the Sargasso Sea off Bermuda. Bulletin of the Peabody Museum of Natural History, 26, 1-125.

Granata L. Caporiacco L. 1949. Ostracods marins recueillis pendant les croissières du Prince Albert 1er de Monaco. Resultalts des Campagnes, Scientific Prince Albert 1er, 109, 1-51.

Marples BJ. 1964. Spiders from some Pacific Islands. Part IV. The Cook Islands and Niue. Pacific Science, 14, 382-388.

Müller G.W. 1894. Die Ostracoden des Golfes von Neapel und der angrezenden Meeres-Abschnitte. Fauna Flora Golf. Neapel, 21, 1-104.

Müller G.W. 1906. Ostracoda. Wissenschaftliche Ergebnisse der Deutschen Tiefsee-Expedition *'Valdivia'* 1989-1899. 8, 29-154.

Müller G.W. 1912. Ostracoden. Das Tierreich, 31, 1-434.

Poulsen E.M. 1973. Ostracoda-Myodocopa. 3b. Halocypriformes-Halocypridae. Conchoecinae. Dana Report, 84, 1-223.

Roe HSJ. Shale DM. 1979. A new multiple rectangular midwater trawl (RMT1+8) and some modifications to the Institute of Oceanographic Sciences' RMT1+8. Marine Biology, 50, 283–288.

Roe HSJ. Baker AdeC. Carson RM. Wild RA. Shale DM. 1980. Behaviour of the Institute of Oceanographic Sciences' rectangular midwater trawls; theoretical aspects and experimental observations. Marine Biology, 56, 247-259.

Sars G.O. 1887. Nye Bidrag til Kundshaben om Middlehavets invertebratfauna. IV. Ostracoda Mediterranea. Archive for Mathematik og Naturvidenskab. XII, 173-324.

Skogsberg T. 1920. Studies on marine ostracods. Part 1. (Cypridinids, halocyprids and polycopids). Zoologiska Bidrag Fran Uppsala, Supplement 1, 1–784.

Chapter 6

Bathymetric Distribution, Species Abundance and Day/Night Variation in Species Composition of Halocyprid Ostracods in the Gulf of Oman

6.1 Abstract

In the Gulf of Oman the physical, chemical and biological processes of the water column are extensively affected by the atmospheric forcing of the northeast monsoon. During the northeast monsoon of 1997, zooplankton samples were collected from the Gulf of Oman at 24° N 58° E, using the multiple rectangular midwater trawl (RMT1 +8) system. A day and a night series of horizontal tows were taken to a depth of 2000 m. Halocyprid ostracods were sorted from the RMT1 samples and analysed. The deep oxygen minimum zone from 400 – 1000 m affected the vertical distribution and species composition of the ostracod community and almost no halocyprids were found in this depth horizon. Diurnal vertical migration of halocyprids was also reduced, but this may be due firstly to the presence of predators, and secondarily to the oxygen minimum zone. The Gulf of Oman data were compared to halocyprids at 30ºN 23ºW where there was no deep oxygen minimum zone.

6.2 Introduction

The Arabian Sea is dominated by intense seasonal activity of atmospheric forcing resulting in the northeast monsoon and southwest monsoon, with two intermonsoon seasons. The surface and subsurface waters are therefore open to extreme physical, chemical and biological change (Morrison et al.1998). The southwest monsoon, occurring August - September, is the most dynamic producing wind speeds of more than 30 knots, with more moderate winds during the northeast monsoon during December – February (Naqvi et al. 2003). The southwest monsoon results in upwelling of the Arabian Sea Water off the Gulf of Oman, leading to high primary production in the surface waters (Rixen and Ittekkot 2005, Naqvi et al. 2010). The degradation of organic material results in depleted oxygen at the surface, where there is also reduced aeration due to a lack of opening to the west by the African continent, to the north by the Asian continent, and to the east by the Indian continent (Morrison et al.1999). During the northeast monsoon air over the Asian land mass cools quicker than Arabian Sea Water, and this together with the Coriolis force, generates northeast winds over the Gulf. The surface waters become increasingly dense due to the high salinity, caused by evaporation exceeding precipitation and lack of significant runoff from the adjacent landmasses. This, together with the cooling effect of the wind, leads to sinking of the dense surface water (Naqvi 2003). There is little effect on nutrient concentration by the high salinity Persian Gulf Water that enters the Gulf of Oman from the Persian Gulf, as the Persian Gulf Water quickly merges with the Arabian Sea Water at around 200 - 300 m (Carton and L'Hegaret 2011). The sinking dense water is extremely low in oxygen as a consequence of the exceptionally high plankton activity during the southwest monsoon, and deepens the oxygen minimum zone (OMZ) to 1000 m or more (Morrison et al. 1999). Below the OMZ lies the Indian Deep Water, originating from the North Atlantic Deep Water imported eastward from the Cape of Good Hope. The Indian Deep

Water, with higher oxygen concentrations, is assisted in its advection from southerly latitudes by the propagation of Kelvin and Rossby waves at the equator (Shetye et al. 1994). Beneath the Indian Deep Water at a depth >3800 m lies the Antarctic Bottom Water (Carton and L'Hegaret 2011).

In 1997, during the northeast monsoon, the RRS *Charles Darwin* undertook the "Scheherezade" cruise to the Gulf of Oman to investigate the influence of upwelling on biological processes. At oceanic station *Discovery* 54001, 24° 12'N, 58° 40'E (Figure 6.1) a series of horizontal tows was made with the multiple rectangular midwater trawl (RMT1+8) system, mesh sizes 0.33 mm and 4.5 mm respectively (Roe and Shale 1979, Roe et al.1980). A flowmeter was used to determine the volume of water filtered and conductivity, temperature and depth (CTD) and oxygen data were collected close to Station 54001. The water column was sampled in 50 m, 100 m and 200 m depth horizons to a depth of 2000 m. Most tows were of 1 h duration and a series of day and night samples were taken at each depth to ascertain the effect of the oxygen minimum zone on diurnal vertical migration. Planktonic halocyprid ostracods were sorted from the RMT 1 samples and analysed for bathymetric distribution, species abundance and day/night species composition.

6.3 Material and Methods

Total zooplankton samples were initially fixed in 5 % seawater formalin and transferred after 24 h into Steadman's preserving fluid (0.5 % propylene phenoxetol, 4.5 % propylene glycol, 5 % formalin seawater solution) before being stored for later analysis at the Natural History Museum, London. In 2006 the Steadman's preserving fluid was replaced by 80 % industrial methylated ethanol. Using a stereoscopic microscope the ostracods were picked and counted from each of the day and night series of samples, starting at the deepest sample and working towards the surface. Over 19,000 ostracods were picked from Station 54001#19, the 150 – 100 m night sample, making species identification from this number of ostracods unmanageable. Therefore, the remaining samples from 100 m to the surface were subsequently sub-sampled using a Fulsom splitter to give either one half, one quarter or one eighth of the original sample, making species identification more manageable. Species identification was undertaken by examining the individual samples and using a Wild M5 stereomicroscope at x 50 magnification. The specimens of each species of halocyprid ostracod were separated into males, females and juveniles and counted separately. The majority of adult halocyprids were large enough to be retained by the mesh size of 0.33 mm of the RMT1. The A-1, A-2 and A-3 juveniles of the larger species, the smaller adult species, such as the males of *Archiconchoecia striata* Müller, 1894 and their juveniles, and even the earliest stages of the larger species, would have been extruded through the mesh. The minimum size of specimen retained was ~ 0.5 mm.

The ostracods from each sample were identified to species and the females, males and juveniles counted. These data were normalised using *in situ* flow data to give the number per $1000m^3$.

6.4 Results

The total halocyprid ostracods from each day and night sample, collected at oceanic Station 54001 have been normalised using *in situ* flow data to give the number of ostracods per $1000m^3$ for the day and night series (Tables 6.1 and 6.2). The data from Tables 6.1 and 6.2 were used to plot ostracod abundance against the physiochemical factors measured by the CTD and oxygen probes, namely salinity (Figures 6.2 and 6.5), temperature (Figures 6.3 and 6.6) and oxygen concentrations (Figures 6.4 and 6.7) using the mean values for each sample range for both the day and night samples. The day salinity profile in the Gulf of Oman (Figure 6.2) showed there was a salinity maximum in the shallow wind-mixed layer, then a rapid decline to a minimum at 100 – 150 m, a slight increase at 200 – 300 m, below which there was a gradual decline to 1400 m. The night salinity profile (Figure 6.5) showed a gradual decline in salinity with increasing depth. Therefore, neither by day nor by night did the salinity profiles show any similarity with the ostracod abundance profiles. Both the day (Figure 6.3) and night (Figure 6.6) temperature profiles showed a steady decline *in situ* temperature with increasing depth, but again there was no indication that the ostracod abundances were being influenced by changing temperature. However, both the day (Figure 6.4) and night (Figure 6.7) oxygen concentration profiles showed declines to values of < 2 ml/l at around 400 m, which coincided with ostracod abundances decreasing to almost zero. From 400 – 1000 m ostracod counts remained very low coinciding with the oxygen minimum zone. Below 1000 m oxygen concentration began to increase again, and the increase coincided with an increase in ostracod abundance. However, above 300 m there is an off-set in the ostracod abundance data relative to the oxygen concentration profile, which is possibly a result of the ostracods being able to tolerate short periods in the low oxygen water and using the low oxygen conditions as a refuge from potential predators.

The results of species identification normalised using *in situ* flow data, for females, males and juveniles are given in Tables 6.3 – 6.8. There were significant differences between the day and night profiles of species richness; the night samples contained almost double the number of species (27 – 30 species) found in the day samples (17 – 18 species). These differences are probably due to sampling, as the day and night series of samples were taken to 1400 m. The additional samples from 1400 – 2000 m were taken at night when species richness reached its maximum.

Plotting the day and night profiles of normalised abundances of females, males and juveniles, provided some evidence for diurnal vertical migration in seven of the species (Figures 6.8 – 6.14). The diurnal vertical migration bar charts have only been plotted from 0 - 500 m, since the number of specimens from 500 – 800 m declined to almost zero. Figure 6.8 showed females, males and juveniles of *Proceroecia procera* Müller, 1894 all migrating towards the surface at night. This was the only species to show diurnal vertical migration in both sexes and juveniles. *Euconchoecia omanensis* Graves, 2011 (Figure 6.9) and *Disconchoecia elegans* Sars, 1866 (Figure 6.11) only the females showed diurnal vertical migration. In Figure 6.10 *Archiconchoecia striata* Müller, 1894 females showed diurnal vertical migration, but it is not known if the males would do so, as they were not caught in the net in insufficient numbers. The adults of *Porroecia porrecta* Claus, 1890 and *Conchoecetta giesbrechti* Müller, 1906 (Figures 6.12 and 6.13) showed reverse migration at night, with the juveniles aggregating around 50 – 100 m at night. Figure 6.14 showed some females, males and juveniles of *Pseudoconchoecia concentrica* Müller, 1906 moving up at night, whilst others were moving down.

6.5 Discussion

This research has shown that the extreme atmospheric forcing of the northeast monsoon, leading to the deep oxygen minimum zone, has a severe impact on halocyprid ostracod abundance. The results show in both the day and night samples a peak of total halocyprid abundance at 0 – 200 m, with a substantial decline from 400 – 1000 m to almost zero, and a marked increase from 1000 – 2000 m (Tables 6.1, 6.2). In contrast, total ostracod abundance profiles, in both day and night data, at 30ºN 23ºW in the northeast Atlantic where abundance peaked at 200 – 300 m, declined far less rapidly from 400 – 600 m and showed a slight maximum in the deep mesopelagic zone down to 1000 m, followed by a gradual decline to 2000 m (Angel, 1979; Table 6.9). The marked contrast between these total ostracod profiles in the two oceans might be correlated with: a) differences in salinity, b) differences in temperature, or c) differences in oxygen concentration. However, the water masses in the northeast Atlantic, below the warm well-oxygenated wind-mixed layer above 200 m, are driven by the North Atlantic Central Water to a depth of 750 m, by the Mediterranean Water from 750 – 1500 m and by the North Atlantic Bottom Water from 1500 m (Angel 1979). The North Atlantic Central Water, a deep homogenous layer formed in the subtropical gyre, has a mean salinity of 35.4 and a mean temperature of 11ºC, the Mediterranean Water has a salinity maximum of 36.6 and mean temperature of 12.2ºC (Fiúza et al. 1998). By comparing data from the Gulf of Oman (Tables 6.10, 6.11) with the salinity and temperature data from 30ºN 23ºW, the two areas have similar salinities and temperatures. However, despite the North Atlantic Central Water having a relatively low oxygen concentration it never reaches the suboxic levels of the Arabian Sea. Below the North Atlantic Central Water, the Mediterranean Sea Water and the North Atlantic Bottom Water both have higher oxygen concentrations (Sverdup et al.1942) than that observed in the Gulf of Oman. This may explain the differences in halocyprid ostracod abundance between the Gulf of Oman samples and the 30ºN 23ºW data.

In the Gulf of Oman data, species richness was at a minimum between 400 – 900 m very likely due to the extremely low oxygen concentrations. Below 1400 m, in the more highly oxygenated water flowing northwards from more southerly latitudes, was a community with richness at its maximum. In contrast, in the Atlantic at 30ºN 23ºW species richness reflected the water mass structure of higher oxygen concentrations, and a maximum of 40 species was reached at 900 - 800 m in the day samples, and a similar maximum at 600 – 500 m in the night samples (Angel 1979).

The species composition from the 1997 samples was compared to that of George and Nair (1980), who reported a maximum number of 32 species in the northern Indian Ocean after analysis of the International Indian Ocean Expedition (IIOE) data.

However, their data were restricted to the upper 200 m, the maximum depth to which the IIOE sampling extended.

The most abundant species was *Euconchoecia omanensis*. However, *Euconchoecia omanensis* and other small epipelagic species also occurred in small numbers in the deeper samples and were probably contaminants which leaked into the deep samples as the nets were being recovered by hauling through shallow near-surface waters. When the RMT1 closes there is not a completely tight seal between the bars, so slight leakage is always a possibility.

In the Gulf of Oman 1997 samples only seven species appeared to be undertaking diurnal vertical migration. All stages of *Proceroecia procera* (Figure 6.8) migrated towards the surface at night. Only the females of *Euconchoecia omanensis* (Figure 6.9) showed clear evidence of migrating towards the surface at night; in males the evidence was only slight and for the juveniles there was none. Females of *Archiconchoecia striata* (Figure 6.10) were clearly migrating up at night; the males of this species were not sampled adequately because of their small size. In *Disconchoecia elegans* (Figure 6.11) the females showed evidence of upward migration at night, but neither males nor juveniles appeared to migrate. Rather unexpectedly the adults of both *Porrecia porrecta* (Figure 6.12) and *Conchoecetta giesbrechti* (Figure 6.13) appeared to be undertaking reverse migration, i.e. moving down from the surface at night, and the juveniles of both these species accumulated at 50 – 100 m at night. The profiles for *Pseudoconchoecia concentrica* (Figure 6.14) imply that some females, males and juveniles were migrating up at night, but others were undertaking reverse migration. A possible explanation for this paradoxical observation may be the impact of their predators. Some of the halocyprid species appeared to be avoiding the upper 50 m at night and so accumulating, and even migrating down to 50 – 100 m. Many of their probable predators were more abundant at night in the upper 50 m. For example, some of the species of myctophid and photichthyid fish (Herring et al. 1999) were tolerant of low oxygen conditions and so by day occurred at depths of 300 - 400 m and migrated up to 100 – 200 m by night. The decapod shrimps of *Pasiphaea marisrubri* Iwasaki, 1989, *Plesionika persica* Kemp, 1925 and *Sergestes semissis* Burkenroad, 1940 (Herring et al. 1999) were also caught at 300 – 400 m by day and migrated in high densities into the upper 200 m at night. Overall the total combined abundances of predatory fish and decapod shrimps were highest at night at 50 – 100 m.

George and Nair (1980) reported that only four of the 32 species collected during the International Indian Ocean Expedition were undergoing diurnal vertical migration. This is in marked contrast with the halocyprids at comparable latitudes in the northeast Atlantic, where Angel (1979) reported that at 30ºN 23ºW twenty one species showed diurnal vertical migration (Angel 1979). George and Nair's (1980) data were restricted to the upper 200 m and so may well underestimate the numbers of diurnally migratory species. Based on the data presented here the intense midwater oxygen minimum both constrains the extent of migrations of the halocyprids and limits the numbers of species migrating. Its influence may not be the primary factor constraining the ostracod migrations, but may be a secondary influence resulting from its regulation of the distribution of the dominant predators of the halocyprids.

6.6 Tables and Figures

Table 6.1. Total halocyprid ostracods per 1000 m^3 for the day series.

Station	Depth (m)	Day/Night	Sample volume (cubic metres)	Percentage sampled	Ostracods	Total	Ostracods Per 1000 cubic metres
54001#27	0 - 50	Day	1279	50.0%	1345	2690	2103
54001#26	50 - 100	Day	1172	25.0%	2244	8976	7659
54001#25	100 - 150	Day	1276	12.5%	1689	13512	10589
54001#03	150 - 200	Day	2589	100.0%	12608	12608	4870
54001#02	200 - 300	Day	2306	100.0%	1026	1026	445
54001#01	300 - 400	Day	2449	100.0%	101	101	41
54001#15	394 - 504	Day	2665	100.0%	13	13	5
54001#14	504 - 605	Day	2549	100.0%	13	13	5
54001#13	600 - 700	Day	2486	100.0%	2	2	1
54001#12	695 - 800	Day	2589	100.0%	6	6	2
54001#11	800 - 896	Day	2325	100.0%	9	9	4
54001#10	896 - 1000	Day	2389	100.0%	95	95	40
54001#24	1007 - 1100	Day	2614	100.0%	231	231	88
54001#23	1100 - 1190	Day	2343	100.0%	79	79	34
54001#22	1195 - 1415	Day	4818	100.0%	84	84	17

Table 6.2. Total halocyprid ostracods per 1000 m^3 for the night series.

Station	Depth (m)	Day/Night	Sample volume (cubic metres)	Percentage sampled	Ostracods	Total	Ostracods Per 1000 cubic metres
54001#21	0 - 50	Night	2574	50.0%	3868	7736	3005
54001#20	50 - 100	Night	2307	25.0%	5563	22252	9645
54001#19	100 - 157	Night	2575	100.0%	19425	19425	7544
54001#06	152 - 201	Night	2746	100.0%	6831	6831	2488
54001#05	201 - 305	Night	2511	100.0%	23	23	9
54001#04	305 - 400	Night	2647	100.0%	371	371	140
54001#18	403 - 497	Night	2704	100.0%	3	3	1
54001#17	497 - 598	Night	2525	100.0%	3	3	1
54001#16	598 - 694	Night	2644	100.0%	2	2	1
54001#09	699 - 800	Night	2654	100.0%	74	74	28
54001#08	800 - 894	Night	2378	100.0%	43	43	18
54001#07	894 - 1016	Night	2468	100.0%	29	29	12
54001#31	1387 - 1600	Night	5117	100.0%	1706	1706	333
54001#30	1600 - 1833	Night	4973	100.0%	1123	1123	226
54001#29	1821 - 2009	Night	5253	100.0%	697	697	133

Table 6.3. Species composition females per 1000 m^3 (day series).

Species / Depth Range (m)	0 - 50	50 - 100	100 - 150	150 - 200	200 - 300	300 - 400	394 - 504	504 - 605	600 - 700	695 - 800	800 - 894	896 - 1000	1007 - 1100	1100 - 1190	1195 - 1415
Archiconchoecia striata	10.95	17.06	1285.27	43.26									0.38	10.24	0.21
Conchoecetta giesbrechti		3.41	81.5	14.68	12.14	7.35	1.88	0.39				2.51			1.25
Conchoecia decipiens				3.48											
Conchoecissa plinthina															0.42
Conchoecissa symmetrica															0.21
Discoconchoecia elegans	4.69	6.83	583.07	1679.03	5.2	1.22		0.78				5.44	14.15		0.21
Euconchoecia hormuzensis		5.97													
Euconchoecia omanensis	136.04	669.8	12.54	7.34	0.87	2.45	0.38						1.91		
Metaconchoecia acuta	4.69	3.41	551.72	13.13								0.84	0.77		
Metaconchoecia arcuata															0.21
Metaconchoecia inflata				2.7	113.18	8.57	1.13					0.42		0.43	
Metaconchoecia subinflata	1.56												3.44		
Orthoconchoecia atlantica				0.77								1.67			0.21
Paraconchoecia oblonga		3.41													
Porrecia porrecta	32.85	525.6	6.27	0.77	0.43		0.38								
Proceroecia procera	15.64	119.45	783.7	0.39	0.87										
Pseudoconchoecia concentrica		71.67	6.27		0.43										

Table 6.4. Species composition males per 1000 m^3 (day series).

Species / Depth Range (m)	50 - 0	100 - 50	150 - 100	200 - 150	300 - 200	403 - 300	504 - 394	605 - 504	700 - 600	800 - 695	896 - 800	1000 - 896	1100 - 1007	1190 - 1100	1415 - 1195
Archiconchoecia striata		3.41													
Conchoecetta giesbrechti	1.56		100.31	7.72	13.44	1.22									0.62
Conchoecia decipiens			6.27												
Conchoecissa symmetrica															1.66
Discoconchoecia elagans	6.25	6.83	338.56	465.04	1.73	0.82						1.26	4.97	0.43	0.21
Euconchoecia omanensis	334.64	1532.42	31.35	3.09	0.43			0.39	0.40				3.06		
Gaussica subedentata												0.42			
Metaconchoecia acuta	1.56	10.24	1015.67	21.24				0.39				1.67	1.15		
Metaconchoecia arcuata															0.21
Metaconchoecia inflata				2.32	54.64	3.67		0.39					1.53	0.43	
Metaconchoecia subinflata	1.56	17.06											0.38		0.21
Paraconchoecia cophogya															0.42
Paraconchoecia macroreticulata															0.21
Paramollicia distans															0.83
Porrecia porrecta	12.51	443.69	43.89				0.38	0.39					2.30		
Proceroecia brachyaskos															0.21
Proceroecia procera	7.82	204.78	344.83	24.72		0.82						0.42	1.15		
Pseudoconchoecia concentrica		61.43	12.54		0.43								0.38		

Table 6.5. Species composition juveniles per 1000 m^3 (day series).

Species / Depth Range (m)	50 - 0	100 - 50	150 - 100	200 - 150	300 - 200	400 - 300	504 - 394	605 - 504	700 - 600	800 - 695	894 - 800	1000 - 896	1100 - 1007	1190 - 1100	1415 - 1195
Alacia alata				0.39	0.87	1.22						0.84			
Conchoecetta giesbrechti	3.13	6.83	1072.10	316.72	95.40	0.41		0.39	0.40			2.09	0.77		0.21
Conchoecissa plinthina															0.83
Conchoecissa symmetrica															1.04
Discoconchoecia elegans	21.89	51.19	2978.06	2230.59	8.67	2.45						21.77	17.98	2.56	
Euconchoecia omanensis	1279.12	3143.34	75.24	2.70	0.87			0.78		0.77	1.29		14.15		
Mamilloecia indica															1.03
Metaconchoecia acuta	17.20	3.41	1015.67	28.58								0.42			
Metaconchoecia inflata				0.77	134.87	8.98	0.38	0.39		0.77	2.58		15.30	3.84	
Metaconchoecia macromma														1.28	0.62
Metaconchoecia subinflata	1.56	10.24													
Mikroconchoecia acuticosta															1.04
Orthoconchoecia atlantica															4.98
Paraconchoecia cophopyga															0.42
Porrecia porrecta	195.47	559.73	75.24		0.43	1.63		0.78		0.77			3.06	4.27	
Proceroecia procera	9.38	34.13	144.20			0.41	0.38						0.38	2.13	
Pseudoconchoecia concentrica	3.13	129.69	25.08	0.39									1.15		

Table 6.6. Species composition females per 1000 m^3 (night series).

Species / Depth Range (m)	0 - 50	50 - 100	100 - 150	150 - 200	200 - 300	300 - 400	394 - 504	504 - 605	600 - 700	695 - 800	800 - 894	896 - 1000	1387 - 1600	1600 - 1833	1821 - 2009
Archiconchoecia striata	13.99	603.38	1135.15	52.44		0.38				7.16	1.26	0.41	0.39		
Archiconchoecissa cucullata													0.2		0.19
Conchoecetta giesbrechti		1.73	115.73	6.19		2.27						0.81	0.20		
Conchoecia decipiens		12.14	9.32												
Conchoecia hyalophyllum			0.39												
Conchoecissa plinthina													4.69		
Conchoecissa symmetrica															
Discoconchoecia elegans	163.17	211.53	1198.45	854.70	0.40	1.89						0.81	0.20	0.20	
Euconchoecia hormuzensis		17.77													
Euconchoecia omanensis	573.43	575.21	4.27	1.46		1.51					1.26		0.39		
Felia dispar													0.2		
Halocypris striata														0.80434	0.76
Huxleyoecia muscatensis														5.6304	4.57
Loricia ctenophora													0.2		
Mamilloecia indica													68.01	6.03	0.19
Metaconchoecia acuta	4.66	6.94	787.57	20.03									0.78		
Metaconchoecia arcuata															
Metaconchoecia glandulosa														13.07	4.57
Metaconchoecia inflata				1.46	0.40	27.20				0.75			0.59	4.02	2.86
Metaconchoecia macromma													1.17		
Metaconchoecia pusilla													10.16	1.81	
Metaconchoecia subinflata		22.54	1.55												
Mikroconchoecia stigmatica													1.17	1.21	1.33
Mollicoecia sp															0.57
Orthoconchoecia atlantica													0.2		
Paraconchoecia cophopyga													1.95	3.42	1.33
Paraconchoecia oblonga													0.2		
Paramollicia dichotoma													3.91	0.60	
Porrecia parthenoda	0.78		1.17												
Porrecia porrecta	2.33	540.96	157.28				0.37				0.42		0.59		
Proceroecia procera	97.90	1563.94	434.56	2.55	0.40										
Pseudoconchoecia concentrica	24.09	13.87	17.86										0.20		

Table 6.7. Species composition males per 1000 m^3 (night series).

Species / Depth Range (m)	50 - 0	100 - 50	157 - 100	201 - 152	305 - 201	400 - 305	497 - 403	598 - 497	700 - 600	800 - 699	894 - 800	1016 - 894	1600 - 1387	1833 - 1600	2009 - 1821
Alacia alata						0.76									
Archiconchoecia striata															
Bathyconchoecia sp													0.20		0.38
Conchoecetta giesbrechti		5.20	147.57	4.73		0.38							0.78		
Conchoecia decipiens		5.20	14.37												
Conchoecia hyalophyllum	0.78		6.21												
Conchoecissa plinthina													4.69	0.40	
Discoconchoecia elegans	3.11	20.81	218.25	503.28		0.38				0.75		1.22	1.76	0.20	0.19
Euconchoecia hormuzensis		15.60													
Euconchoecia omanensis	581.97	703.94	2.33	1.09						0.38	0.84	0.41	0.39		
Felia dispar													2.15		
Halocypris striata														3.42	1.14
Huxleyoecia muscatensis														3.42	2.47
Mamilloecia indica													30.49	7.04	
Metaconchoecia acuta	2.33		309.13	16.02									0.39		
Metaconchoecia glandulosa														1.01	2.28
Metaconchoecia inflata					2.79	40.80				1.13	3.36		1.37	0.20	2.86
Metaconchoecia macromma													2.93		
Metaconchoecia pusilla													11.53	7.64	
Metaconchoecia subinflata	0.78	6.94	0.39									2.43			
Mikroconchoecia stigmatica													1.56	2.21	1.33
Mollicoecia sp														0.40	0.95
Orthoconchoecia atlantica			4.27												
Paraconchoecia cophopyga													3.32	5.83	0.76
Paramollicia dichotoma													1.56	0.20	0.19
Porrecia parthenoda			0.78												
Porrecia porrecta	2.33	476.81	161.17					0.40							
Proceroecia brachyaskos													0.20		
Proceroecia procera	6.22	606.85	656.31	52.44						1.51	0.42			0.40	
Pseudoconchoecia concentrica	21.76	22.54	16.31												

Table 6.8. Species composition juveniles per 1000 m^3 (night series).

Species / Depth Range (m)	50 - 0	100 - 50	157 - 100	201 - 152	305 - 201	400 - 305	497 - 403	598 - 497	700 - 600	800 - 699	894 - 800	1016 - 894	1600 - 1387	1833 - 1600	2009 - 1821
Alacia alata					0.40	1.89									
Bathyconchoecia georgi													0.20		
Bathyconchoecia sp														0.40	0.38
Conchoecetta giesbrechti	3.89	1.73	163.50	111.07	0.40	0.38				0.75	1.26	0.41	0.78		
Conchoecia decipiens			3.88												
Conchoecia hyalophyllum			2.72												
Discoconchoecia elegans	136.75	303.42	1391.46	831.76				0.40		12.43	1.26	2.84	14.27	3.82	
Euconchoecia omanensis	1335.66	1522.32	9.32	0.36	0.40				0.38	2.64	0.42	2.43	1.17	1.21	
Felia dispar													3.32		
Halocypris striata														36.20	15.61
Huxleyoecia muscatensis													4.30	30.97	55.40
Mamilloecia indica													40.06	12.27	1.33
Metaconchoecia acuta	2.33		376.70	21.49									0.39		
Metaconchoecia glandulosa														1.41	1.71
Metaconchoecia inflata					3.98	61.58		0.40	0.38	0.38	5.47		10.75	36.20	25.51
Metaconchoecia macromma													3.71		
Metaconchoecia pusilla													4.30	35.19	1.71
Metaconchoecia subinflata			0.39												
Mikroconchoecia stigmatica													22.67	0.60	0.57
Mollicoecia sp															0.38
Orthoconchoecia atlantica													0.20		
Paraconchoecia cophopyga													3.71	10.66	2.09
Paramollicia dichotoma													6.06	12.07	1.71
Porrecia porrecta	13.21	1905.50	48.16			0.38	0.74				0.84		26.19		
Proceroecia brachyaskos													2.15		
Proceroecia procera	1.55	414.39	111.07			0.38		0.40			1.26				
Pseudoconchoecia concentrica	12.43	64.15	36.12												

Table 6.9. Total halocyprid ostracod abundance for day and night samples at N.E. Atlantic station 30ºN 23ºW (data from Angel 1979).

Sample depth range (metres)	Ostracods per 1000 cubic metres Day	Ostracods per 1000 cubic metres Night
10 - 0	0	5750
25 - 10	0.7	8210
50 - 25	80	6910
100 - 50	970	2270
200 - 100	4980	4350
300 - 200	5500	1890
400 - 300	2870	1970
500 - 400	2210	1020
600 - 500	880	460
700 - 600	350	200
800 - 700	230	310
900 - 800	290	260
1000 - 900	120	170
1250 - 1000	110	140
1500 - 1250	59	79
2000 - 1500	43	24

6.10. Total halocyprid ostracod abundance for salinity, temperature and oxygen concentrations in Gulf of Oman day samples.

Sample depth range (metres)	Ostracods per 1000 cubic metres	Salinity psu	Temp (ºC)	Oxygen mls per litre
0 - 50	2103	36.5	23.1	204.4
50 - 100	7659	36.3	21.9	117.3
100 - 150	10589	36.0	19.4	3.3
150 - 200	4870	36.1	18.4	2.5
200 - 300	445	36.2	17.0	2.8
300 - 400	41	36.2	15.3	2.7
394 - 504	5	35.9	13.6	1.5
504 - 605	5	35.7	12.3	1.9
600 - 700	1	35.7	11.5	3.1
695 - 800	2	35.6	10.8	5.2
800 - 896	4	35.5	10.1	6.5
896 - 1000	40	35.5	9.3	7.6
1007 - 1100	88	35.4	8.5	8.9
1100 - 1190	34	35.3	7.7	11.4
1195 - 1415	17	35.2	6.6	19.6

6.11. Total halocyprid ostracod abundance for salinity, temperature and oxygen concentrations in Gulf of Oman night samples.

Sample depth range (metres)	Ostracods per 1000 cubic metres	Salinity psu	Temp (ºC)	Oxygen mls per litre
0 - 50	3005	36.5	23.1	204.4
50 - 100	9645	36.3	21.9	117.3
100 - 157	7544	36.0	19.4	3.2
152 - 201	2488	36.1	18.4	2.5
201 - 305	9	36.2	17.0	2.8
305 - 400	140	36.2	15.2	2.7
403 - 497	1	35.9	13.6	1.5
497 - 598	1	35.7	12.4	1.8
598 - 694	1	35.7	11.6	3.0
699 - 800	28	35.6	10.8	5.2
800 - 894	18	35.5	10.1	6.5
894 - 1016	12	35.5	9.2	7.6
1387 - 1600	333	35.1	5.4	35.5
1600 - 1833	226	34.9	4.1	58.8
1821 - 2009	133	34.9	3.3	76.7

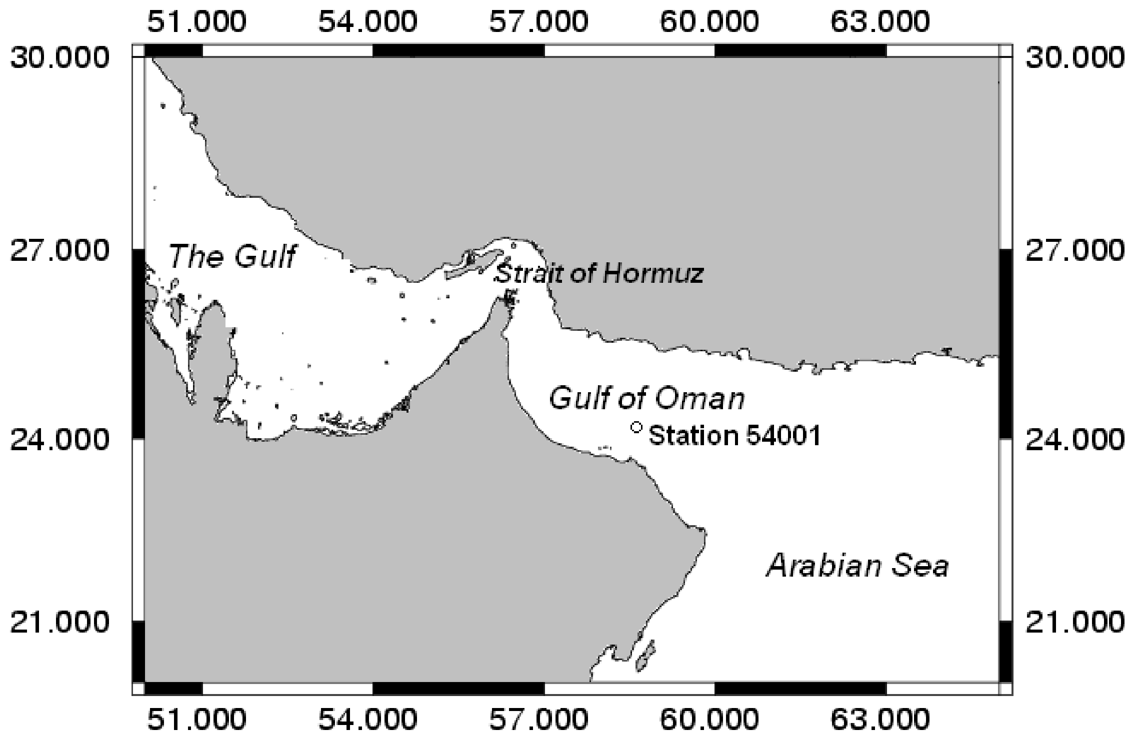


Figure 6.1. Position of Station 54001 in the Gulf of Oman.

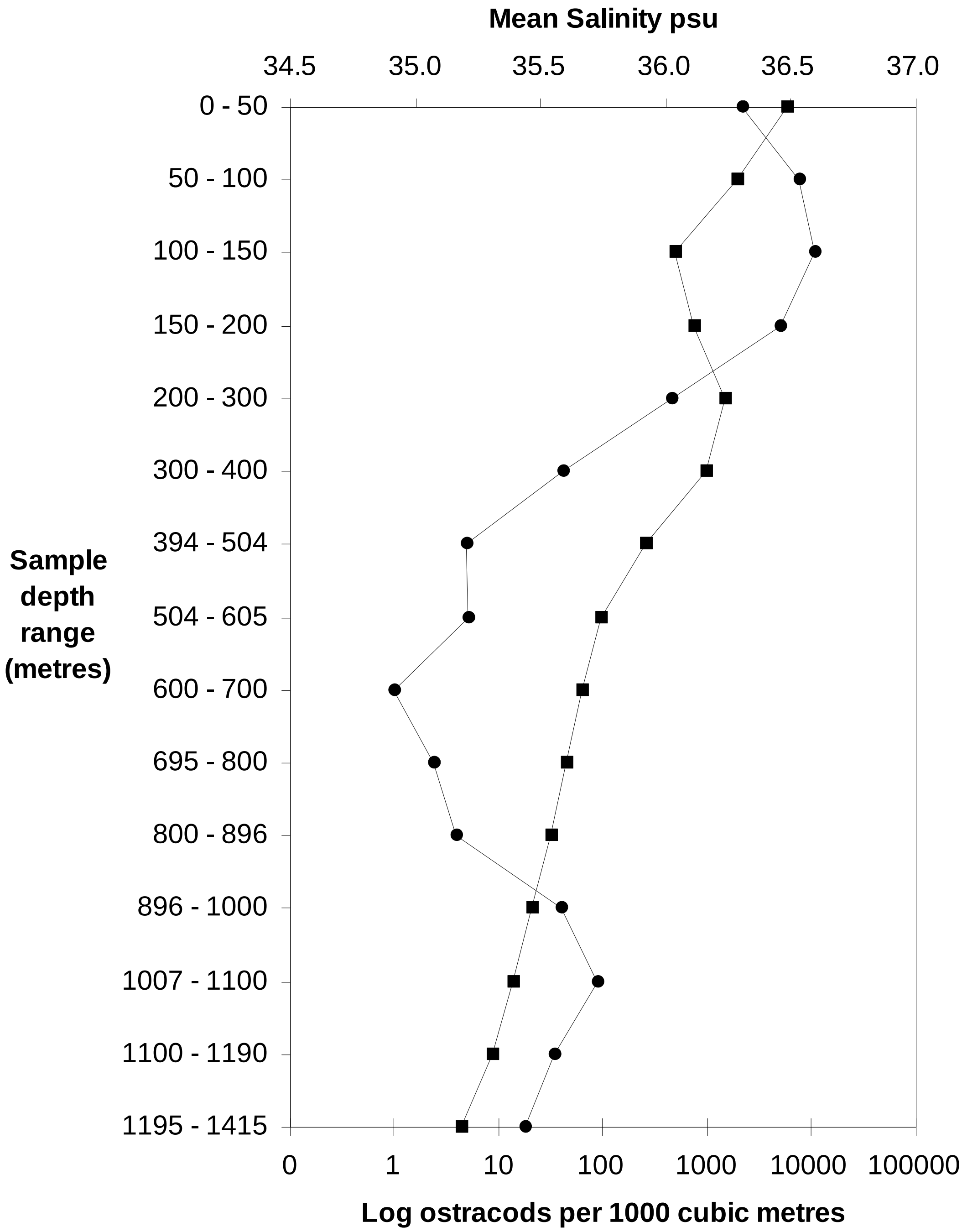


Figure 6.2. Total ostracods per 1000 m^3 against salinity for the day series (● Ostracods per 1000 cubic metres ■ Mean salinity psu).

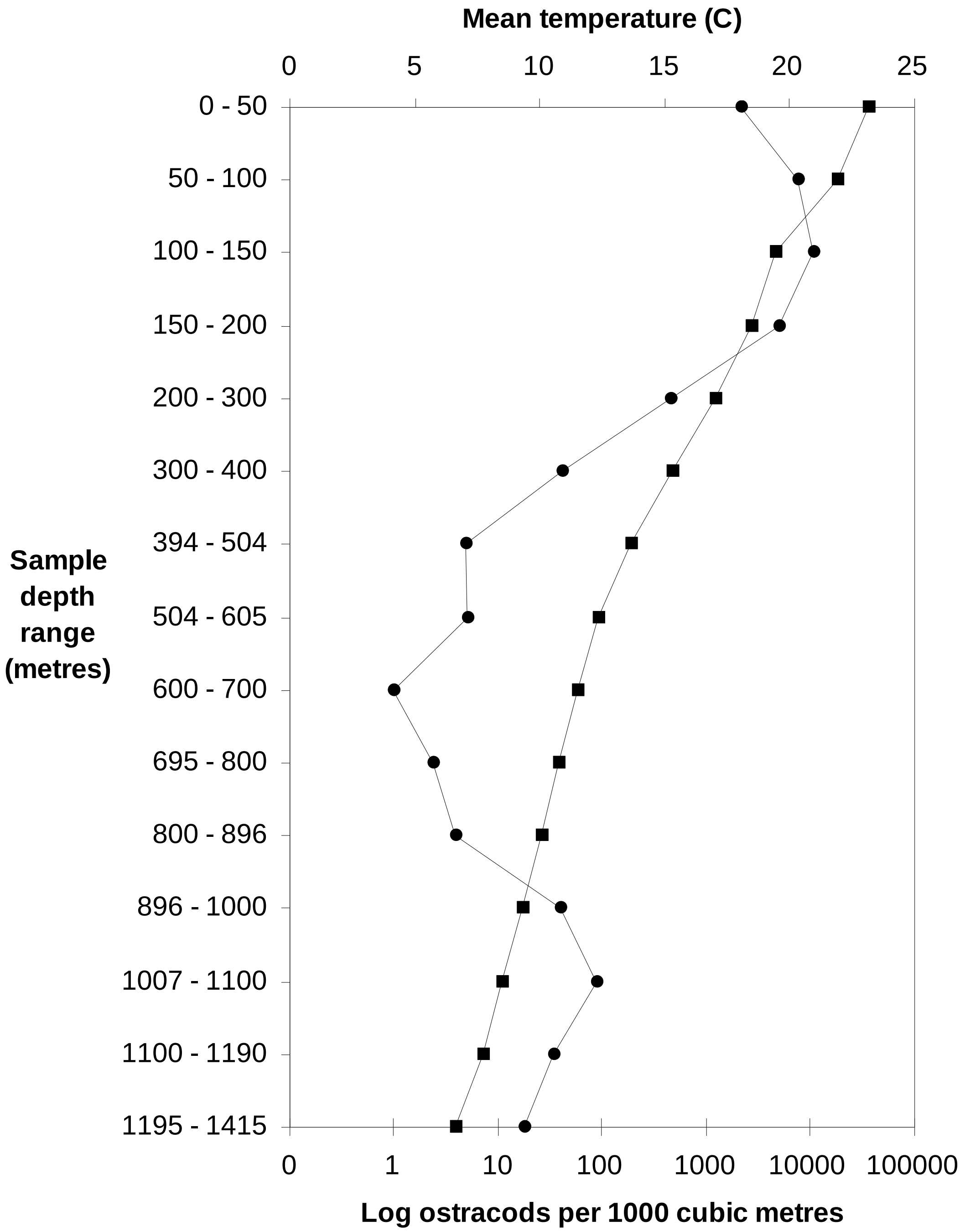


Figure 6.3. Total ostracods per 1000 m^3 against temperature for the day series (● Ostracods per 1000 cubic metres ■ Mean temperature (ºC)).

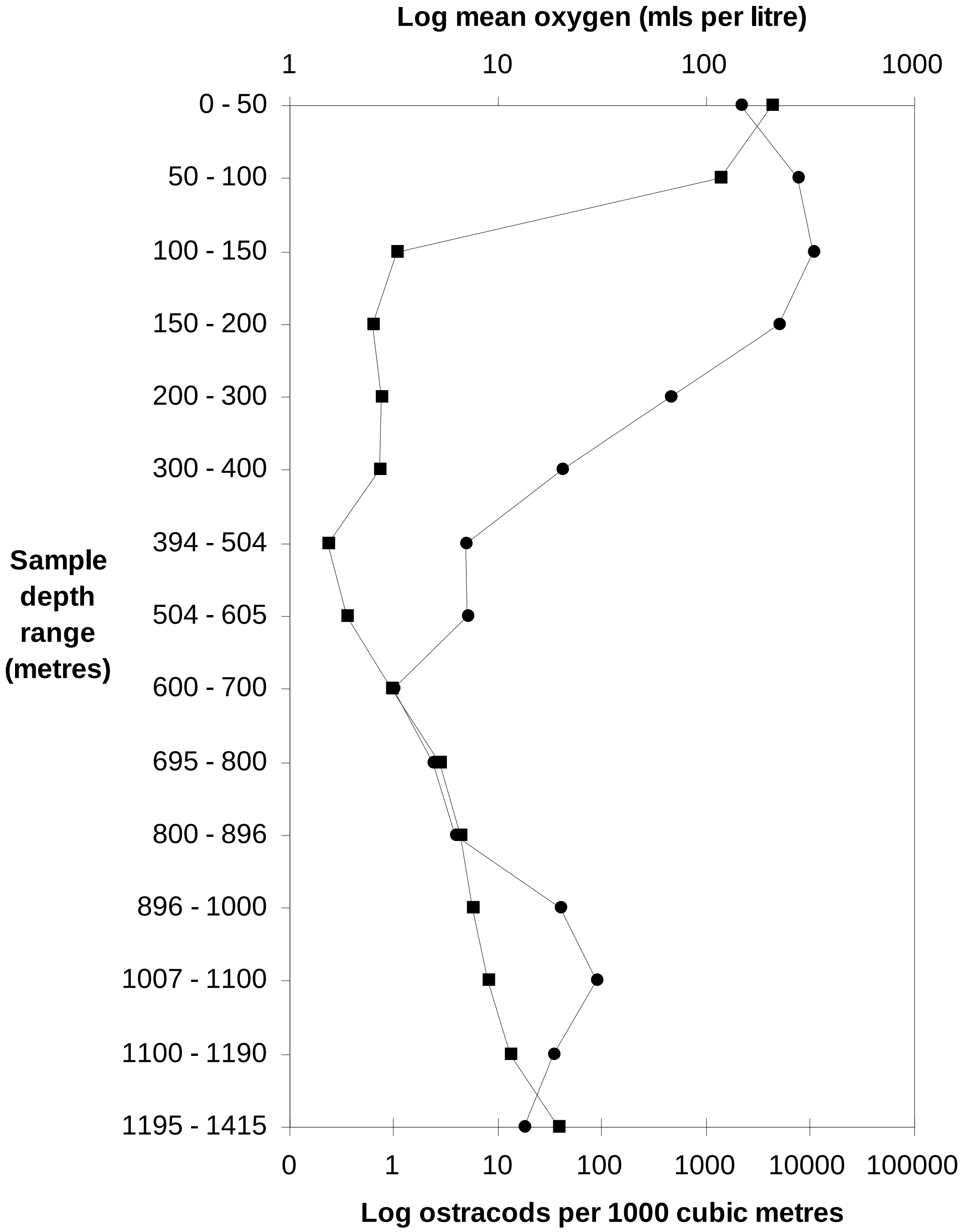


Figure 6.4. Total ostracods per 1000 m^3 against oxygen concentration for the day series (● Ostracods per 1000 cubic metres ■ Mean oxygen (mls per litre)).

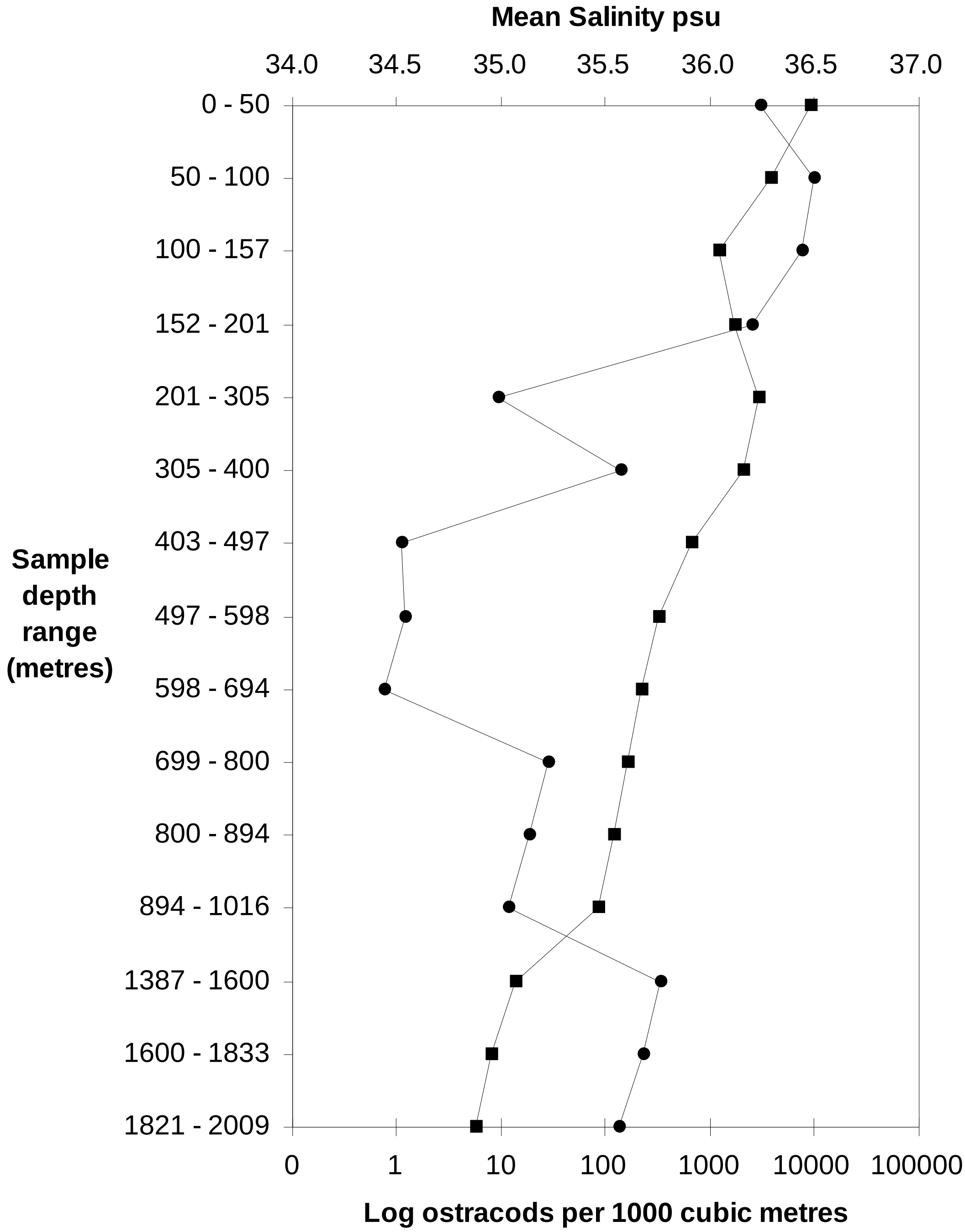


Figure 6.5. Total ostracods per 1000 m^3 against salinity for the night series (● Ostracods per 1000 cubic metres ■ Mean salinity psu).

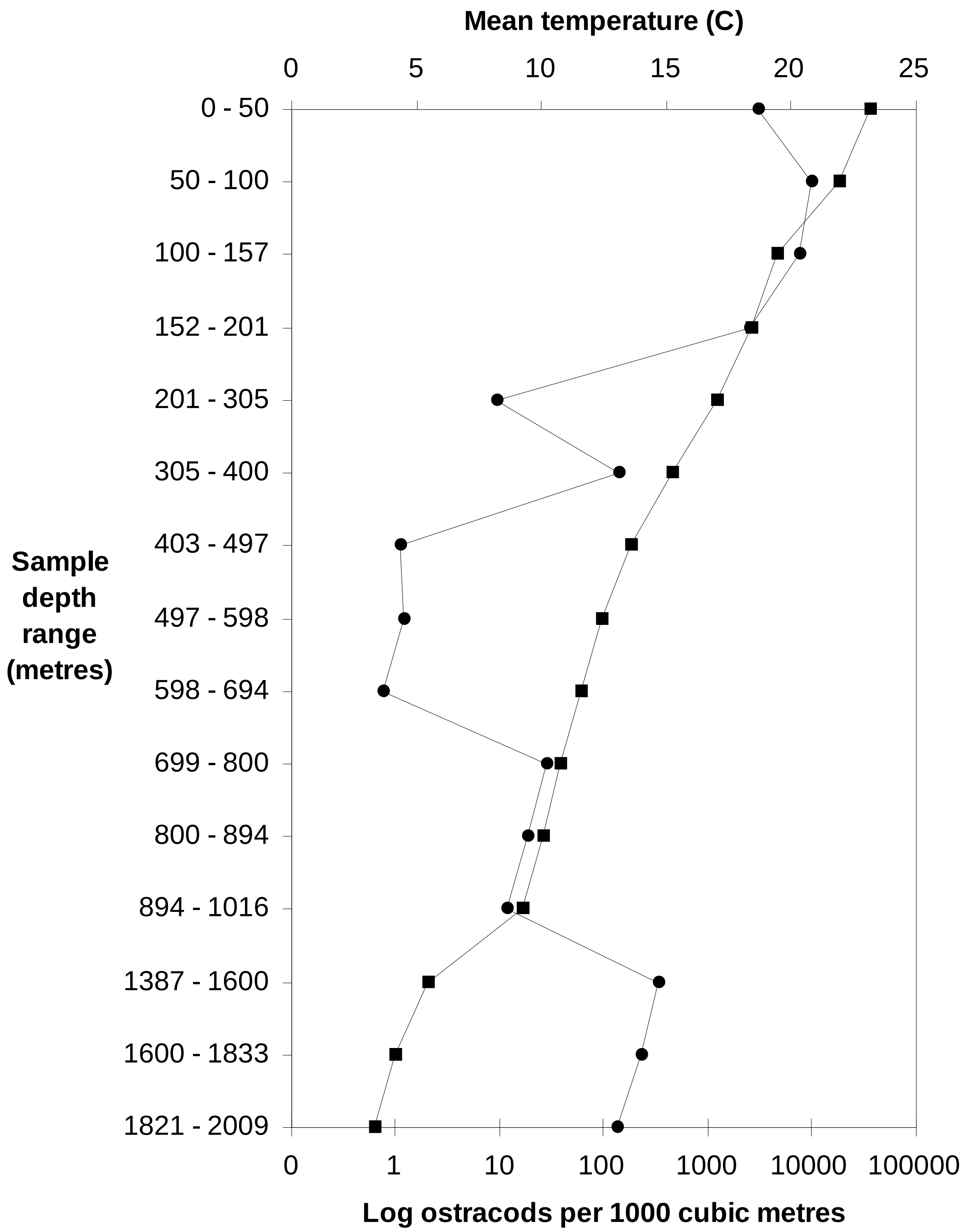


Figure 6.6. Total ostracods per 1000 m^3 against temperature for the night series (● Ostracods per 1000 cubic metres ■ Mean temperature (ºC)).

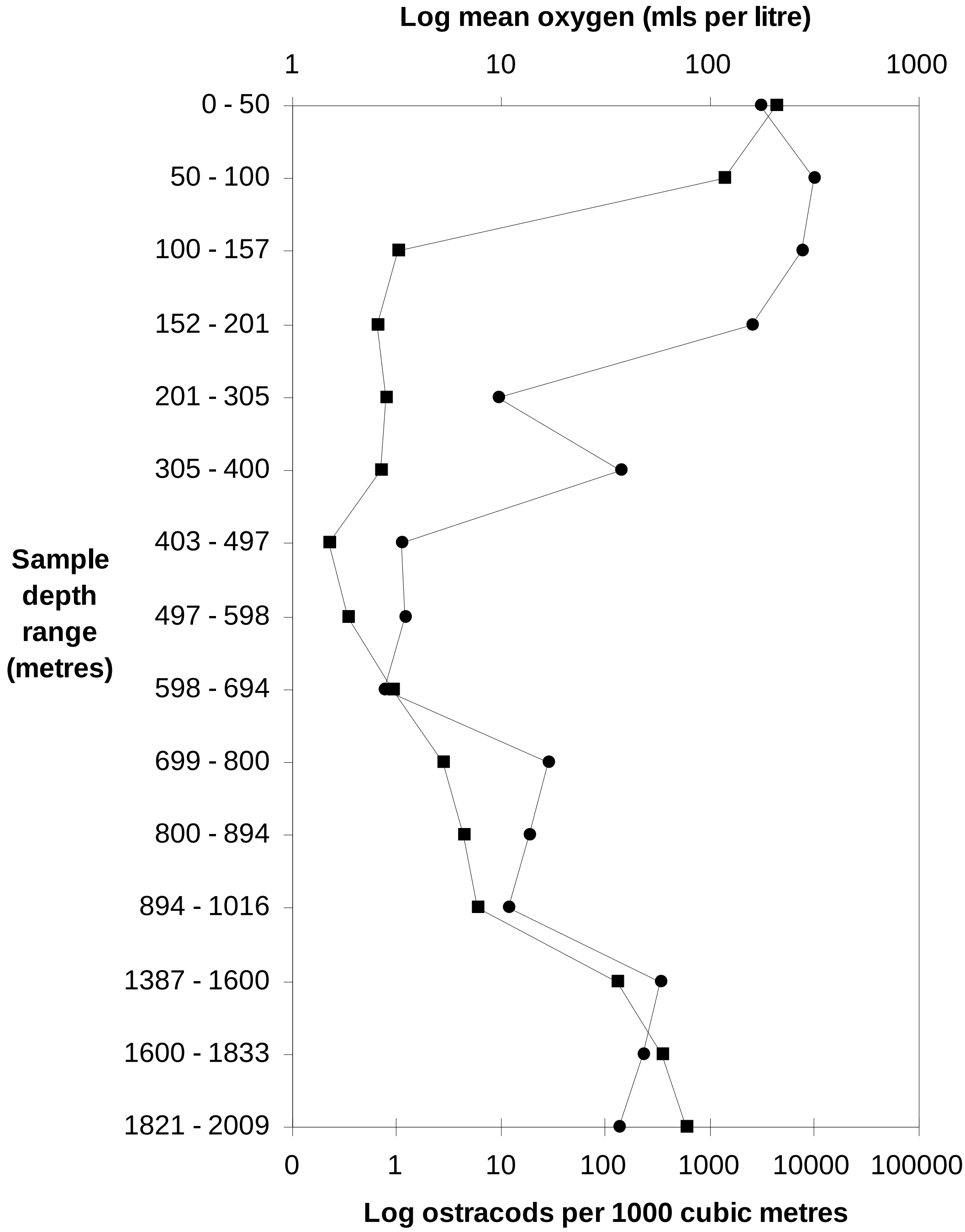
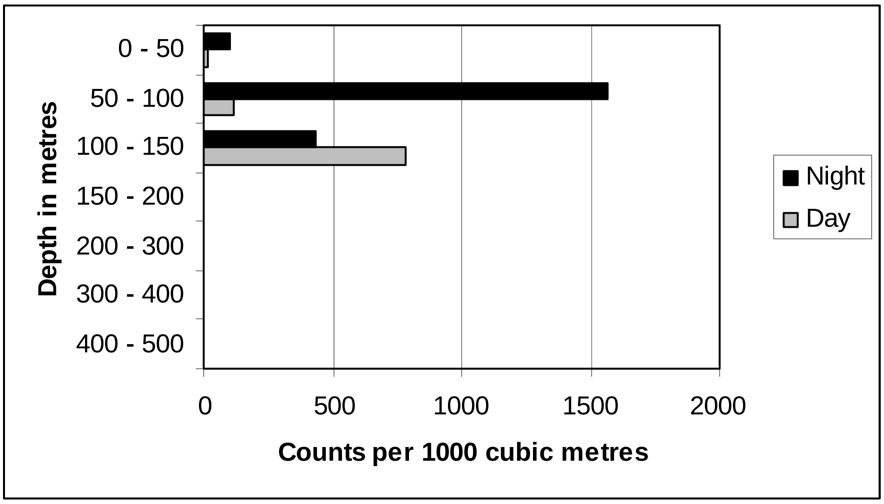
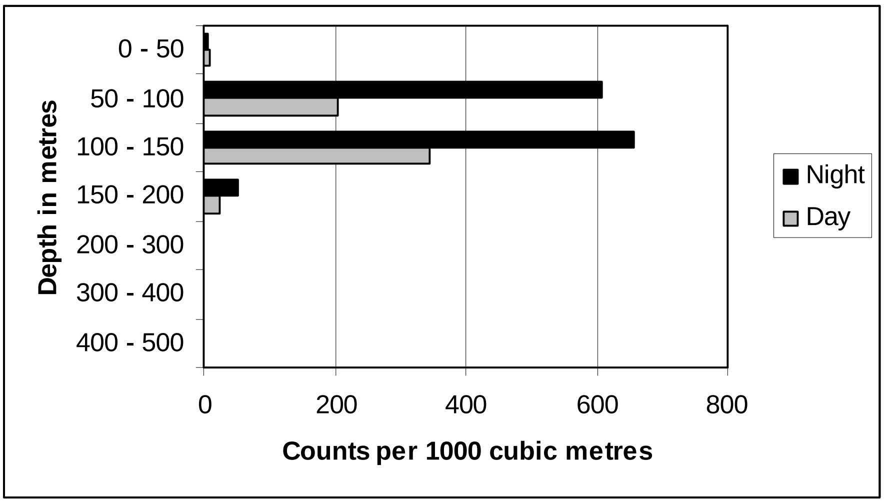


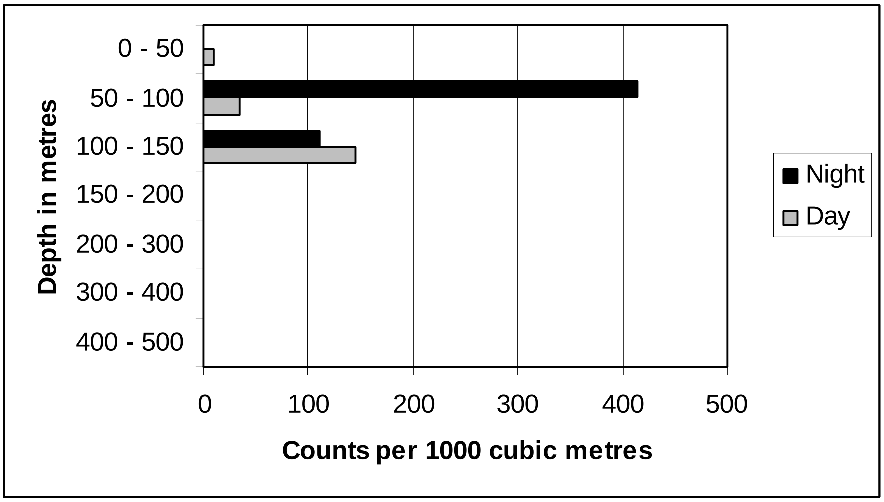
Figure 6.7. Total ostracods per 1000 m^3 against oxygen concentration for the night series
(● Ostracods per 1000 cubic metres ■ Mean oxygen (mls per litre)).



Female

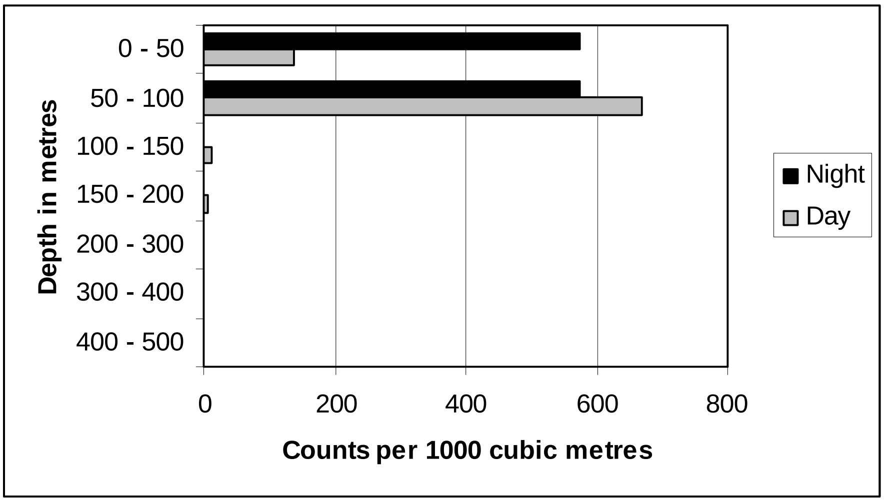


Male

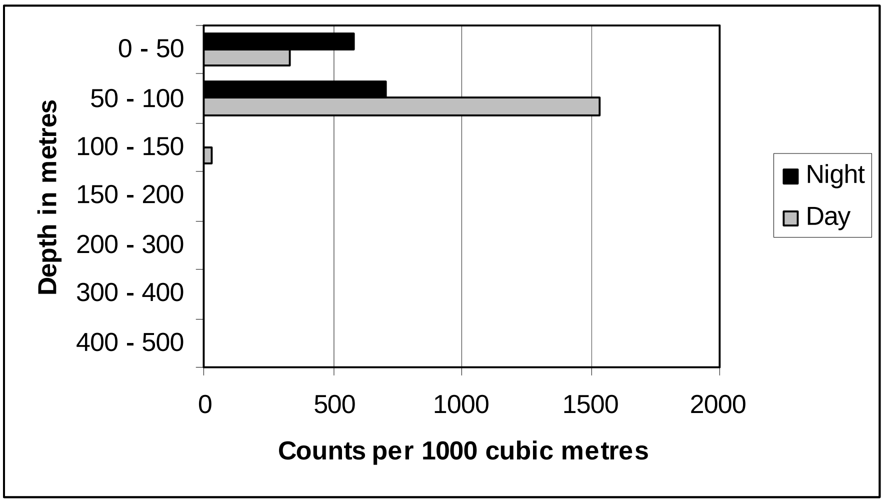


Juvenile

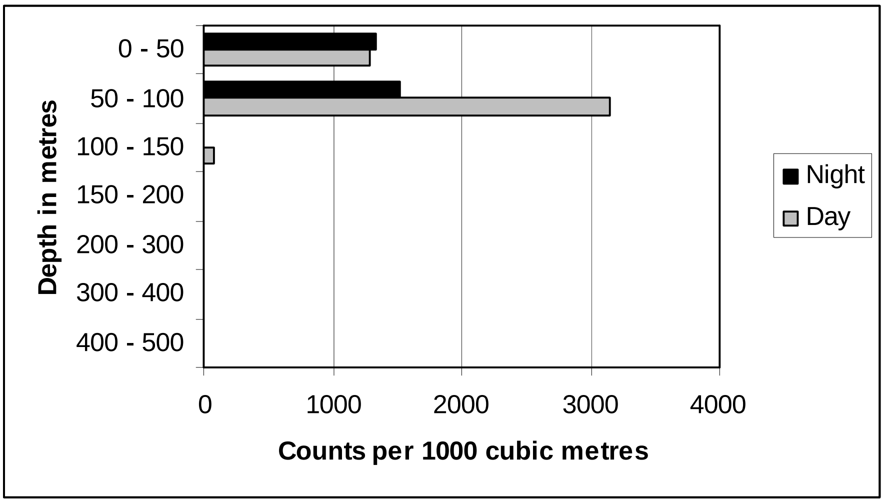
Figure 6.8. Diurnal vertical migration of *Proceroecia procera*.



Female

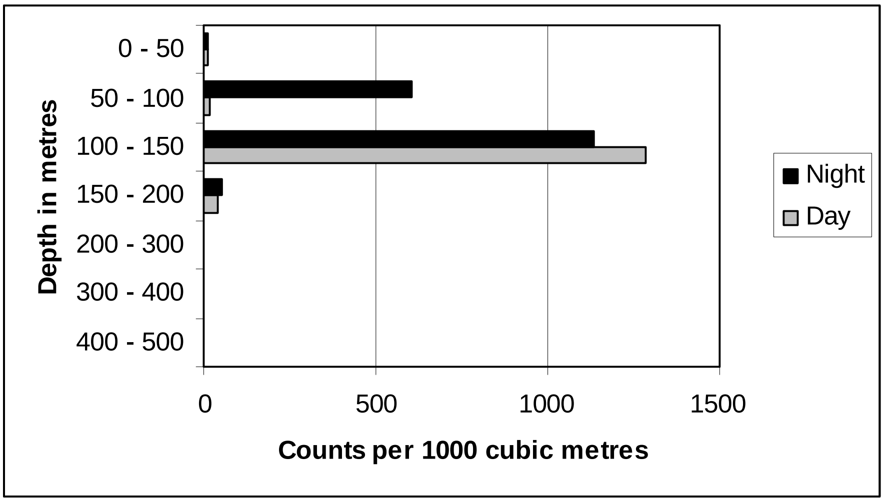


Male



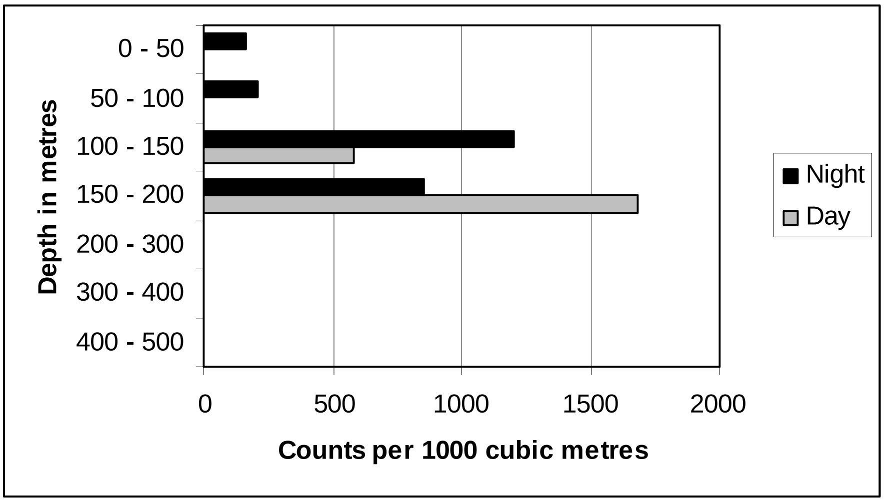
Juvenile

Figure 6.9. Diurnal vertical migration of *Euconchoecia omanensis.*

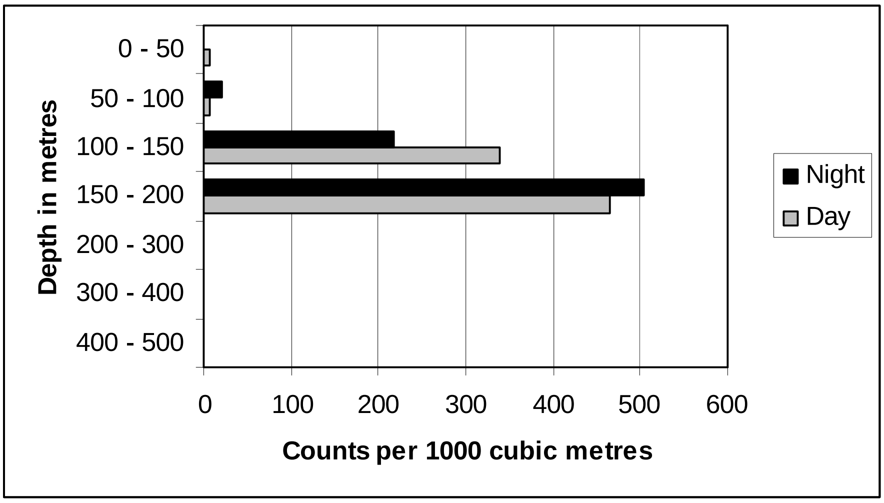


Female

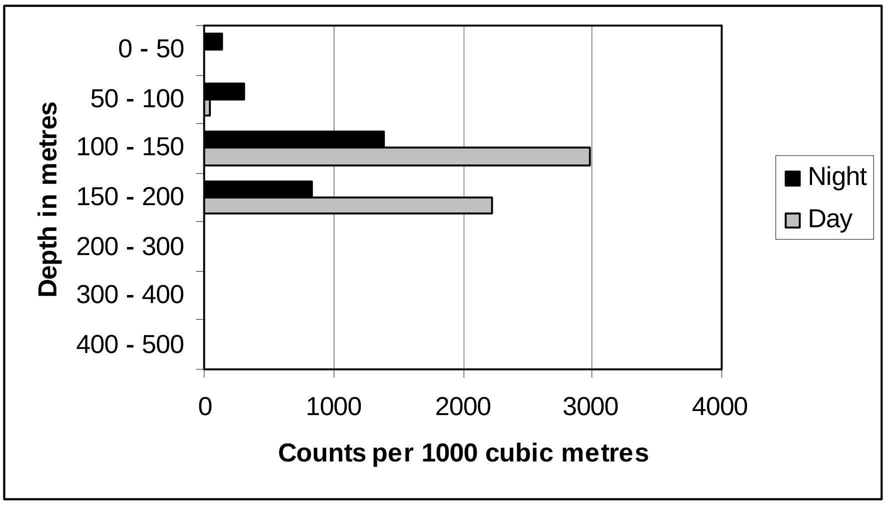
Figure 6.10. Diurnal vertical migration of *Archiconchoecia striata.*



Female

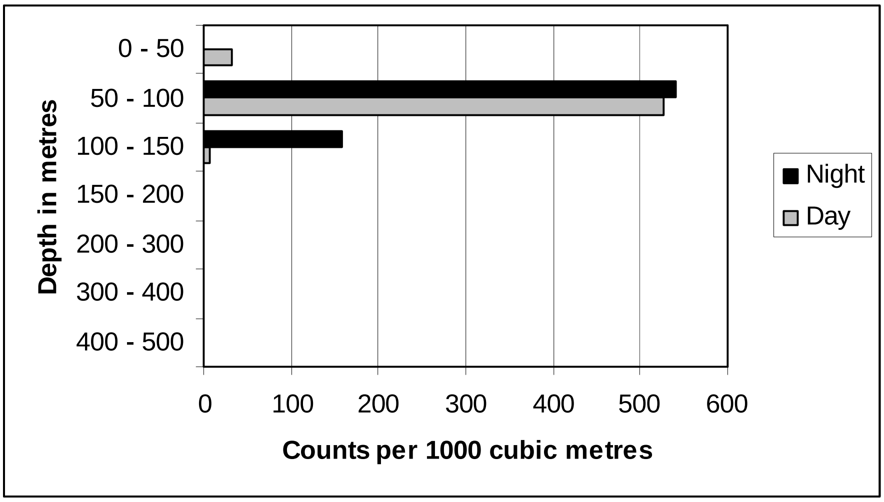


Male

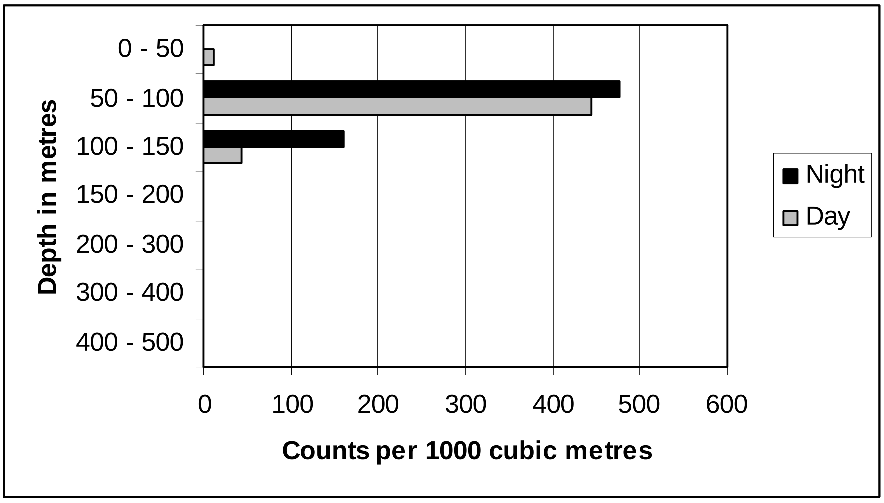


Juvenile

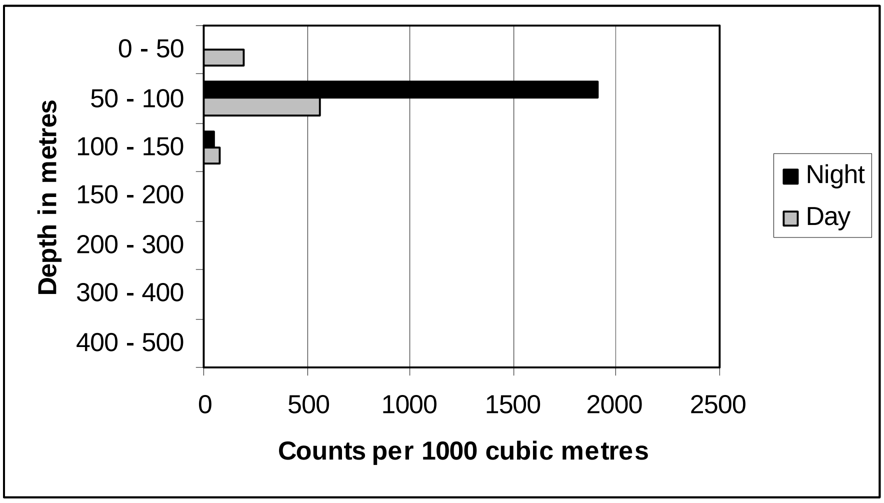
Figure 6.11. Diurnal vertical migration of *Disconchoecia elegans.*



Female

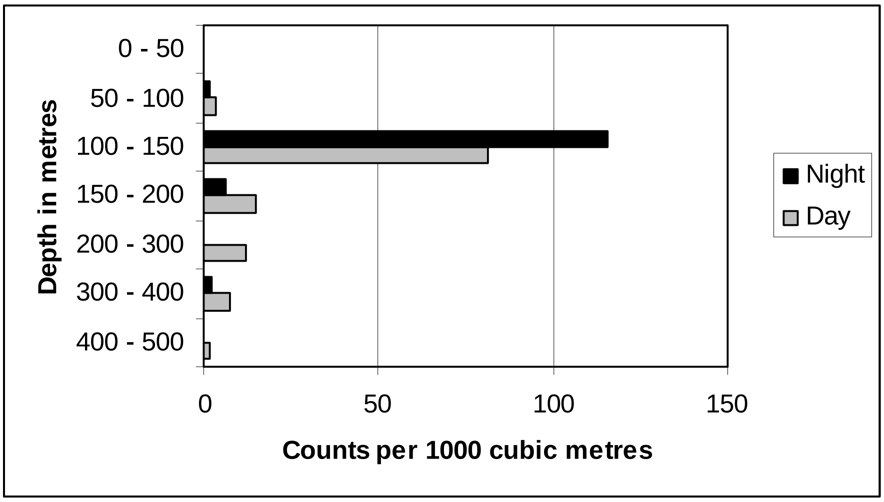


Male

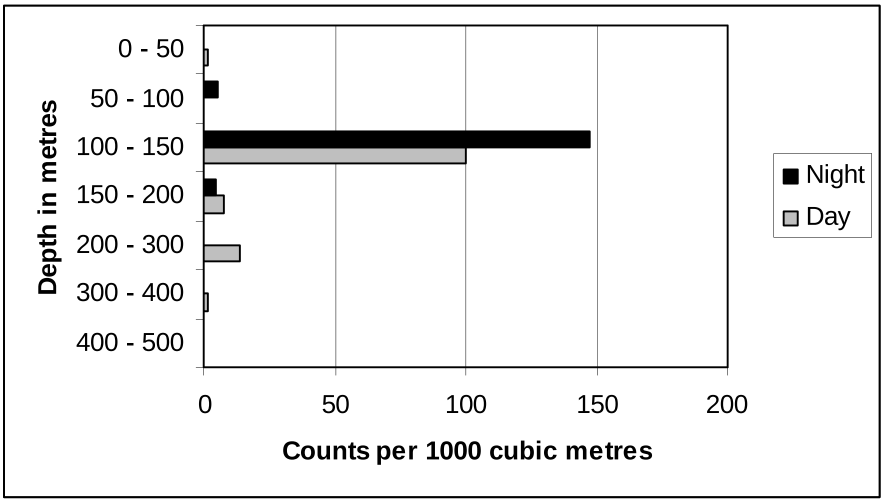


Juvenile

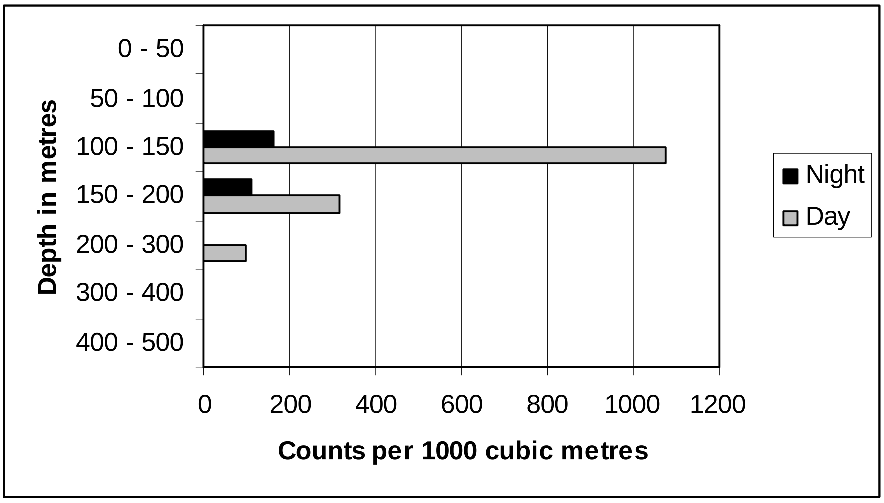
Figure 6.12. Diurnal vertical migration of *Porrecia porrecta*.



Female

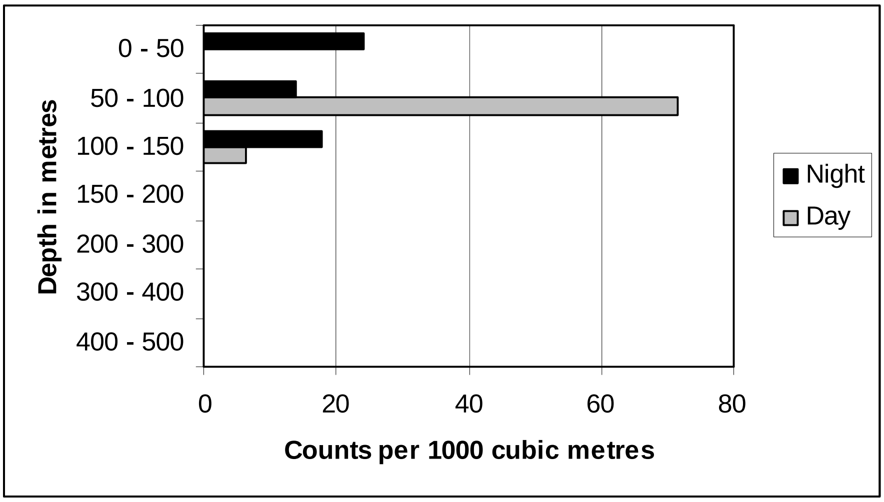


Male

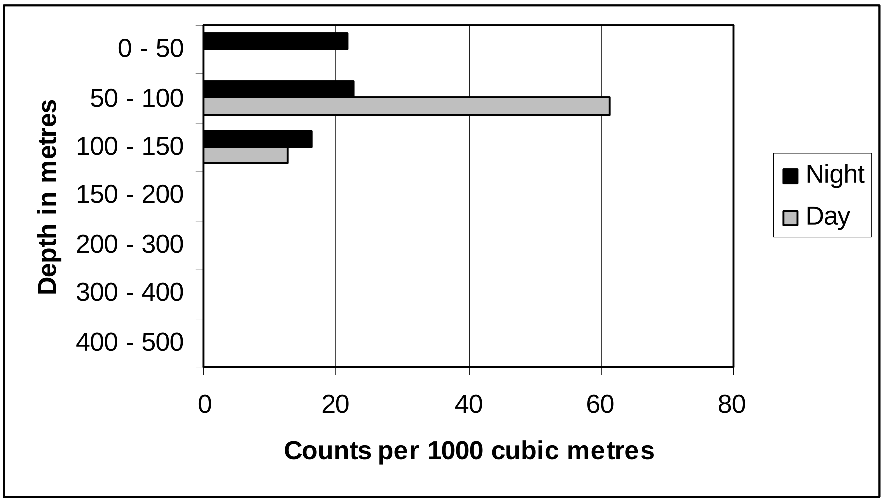


Juvenile

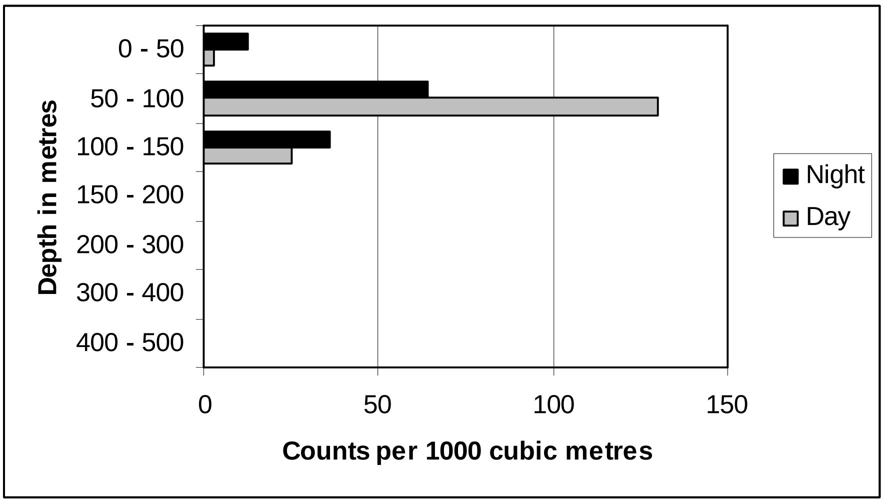
Figure 6.13. Diurnal vertical migration of *Conchoecetta giesbrechti*.



Female



Male



Juvenile

Figure 6.14. Diurnal vertical migration of *Pseudoconchoecia concentrica*.

6.7 References

Angel MV. 1979. Studies on Atlantic halocyprid ostracods: their vertical distributions and community structure in the central gyre region along latitude 30°N from off Africa to Bermuda. Progress in Oceanography, 8, 1-122.

Carton X. L'Hegaret P. 2011. Mesoscale variability of water masses in the Arabian Sea as revealed by ARGO floats. Ocean Science Discussions, 8, 1369-1402.

Fiúza AFG. Hamann M. Ambar I. Díaz del Rio G. González N. Cabanas JM. 1998. Water masses and their circulation off western Iberia during May 1993. Deep Sea Research I, 45, 7, 1127- 1160.

George J. Nair V.R. 1980. Planktonic ostracods of the Northern Indian Ocean. Mahasagar-bulletin of the National Institute of Oceanography, 13, 1, 29-44.

Herring PJ. Howell PR. Pugh PR. 1999. Scheherezade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb – 30 Apr 1997. No 16, Fish, decapod shrimps and siphonophores: abundances and size data. Leg1. 12 Feb – Mar 1997 (Unpublished manuscript).

Morrison JM. Codispoti LA., Gaurin S. Jones, B. Magnhnani V. Zheng Z. 1998. Seasonal variation of hydrographic and nutrient fields during the US JGOFS Arabian Sea Process Study. Deep Sea Research II, 45, 2053 – 2102.

Morrison JM. Codispoti LA. Sharon L. Wishner K. Flagg C. Gardner WD. Gaurin S. Naqvi SWA. Magnhnani V. Prosperie L. Gundersen JS. 1999. The oxygen minimum zone in the Arabian Sea during 1995. Deep Sea Research.Part II : 46, 1903 – 1931.

Naqvi SWA. Naik H. Narvekar PV. 2003. The Arabian Sea. In: Biogeochemistry of Marine Systems, Ed: K. Black and G. Shimmield, Biological Sciences Series, Ch 6, 157 – 207.

Naqvi SWA. Moffet JW. Gauns MU. Narvekar PV. Pratihary AK. Naik H. Shenoy DM. Jayakumar DA. Goepfert TJ. Patra PK. Al-Azri A. Ahmed SI. 2010. The Arabian Sea as a high-nutrient, low-chlorophyll region during the late Southwest Monsoon, Biogeosciences, 7, 2091 – 2100.

Rixen T. Ittekkot V. 2005. Nitrogen deficits in the Arabian Sea, implications from a three component mixing analysis, Deep Sea Research II 52 (2005) 1879 – 1891.

Roe HSJ. Shale DM. 1979. A new multiple rectangular midwater trawl (RMT1+8) and some modifications to the Institute of Oceanographic Sciences' RMT1+8. Marine Biology, 50, 283–288.

Roe HSJ. Baker AdeC. Carson RM. Wild RA. Shale DM.. 1980. Behaviour of the Institute of Oceanographic Sciences' rectangular midwater trawls; theoretical aspects and experimental observations. Marine Biology, 56, 247-259

Shetye SR. Gouveia AD. Shenoi SSC. 1994. Circulation and water masses of the Arabian Sea north of 10ºN. Journal of Earth System Science, 103, 2, 107-123.

Sverdrup HU. Johnson MW. Fleming RH. 1942. The Oceans: Their Physics, Chemistry and General Biology. New York: Prentice Hall, 1-1087.

Chapter 7

7.1 General Discussion

This research has shown that in comparison to other zooplankton groups halocyprid ostracods have not been well studied in the Indian and Pacific Oceans. Their small body size of 0.5 – 3 mm, a lack of understanding of their ecological role, as well as a dearth of scientific expertise in the group has inhibited the advance of knowledge of these abundant and important crustaceans (Angel 2010).

The plankton samples collected in 1997 represent a “snapshot” of the life in the water column at one particular moment in time. However, this type of sampling does give a good representation of the spatial distribution pattern of ostracods both at the community and at the specific level. Angel et al. (1982) demonstrated that repeated sampling over a 36 h period, at a depth of 1000 m using the RMT1+8 trawl, showed comparatively little variability in numerical abundance of individual species and no evidence for diurnal vertical migration as a source of variability at this depth. Angel (1984) described a further series of repeat sampling, using the RMT1+8 net, over a 48 h period carried out at 44ºN 13ºW. Zooplankton samples were collected at 100 m, 250 m, 450 m, and 600 m depth horizons. Each sample involved the filtration of approximately 2,800 m^3 of water and the results showed an unexpected stability in species composition and relative abundance in the deeper two sets of samples.

7.2 Taxonomy

The earliest taxonomic studies of the group were carried out in the mid to late 19th century by Dana (1849), Brady (1880), Müller (1890) and Claus (1891). The criteria they used to distinguish species were the characteristics of carapace size and shape, the structures of the frontal organs, and the first and the second antennae. Many of these early descriptions failed to distinguish between pairs or groups of closely related species. Despite over 200 species of halocyprid ostracod having been described (Angel et al. 2007) taxonomic confusion still persists in the group.

This thesis has focused on resolving some of the complex taxonomic problems that were presented by analysis of the samples from the Gulf of Oman. In the northern Arabian Sea several species have previously been misidentified. This was probably a result of the assumption that many of the halocyprid species occur throughout the oceans (Poulsen 1977). However, this research has shown that several species, some of which are dominant components of the zooplankton assemblages like the *Euconchoecia* Müller, 1890 species have previously been misidentified, and when critically compared with type material have proved to be novel (Graves 2011). Several of the other species need to be critically examined to determine if they to are new or identifiable as somewhat variable ubiquitous species. The study of *Mamilloecia* Graves, 2012 showed that *Paraconchoecia* Müller, 1890 is polyphyletic, and many of the other species presently classified in the genus are also sufficiently disparate from the designated type *Paraconchoecia spinifera* Claus, 1891 to be classified in new genera. So further studies are needed of *Paraconchoecia* and from evidence from these Gulf of Oman samples some of the other genera such as *Paramollicia* Poulsen, 1973 and *Proceroecia* Kock, 1992, also need to be critically re-evaluated.

Unfortunately the material from the Gulf of Oman was unsuitable for sequencing studies, as it had been preserved in formaldehyde which fragments the DNA. Ideally specimens to be used in molecular analyses need to be identified at sea and deep frozen at -60°C for later analysis (Angel 2010). Collecting suitable material is fraught with difficulties, for example, when trawling deep nets in tropical waters the catches are killed as a result of the nets being hauled through the warm surface waters as they are retrieved (Angel pers. com.). Sampling of ostracods in the Atlantic Ocean specifically for molecular analysis has been carried out from the RV *Ronald H. Brown* in 2006 and the German research vessel *Polarstern* in 2007. The objectives of these two cruises conducted under the aegis of the Census of Marine Zooplankton (CMarZ) were to compile a full inventory of holoplankton in the tropical and subtropical Atlantic Ocean and to barcode as many species as possible for the Census of Marine Zooplankton (Wiebe et al. 2010). On both cruises halocyprids were picked out fresh from the catches, identified and deep frozen for molecular analysis of the CO1 gene together with voucher material to validate the live identifications. Special attention was given to keeping the cod-end bucket of the sampling net cool as soon as it was retrieved. The catches were immediately subdivided into aliquots. One quarter was preserved in 5% seawater formalin for later morphological study, half was preserved in 100% ethanol which was used as the main source for barcoding material, and another quarter was retained unpreserved for immediate examination of live specimens. The results of the sequencing of halocyprids from these cruises are being written up (Nigro, personal communication). These results have shown that the molecular analyses are generally consistent with the morphological identifications except for a few critical taxa (namely *Mikroconchoecia* Claus, 1891, *Halocypris* Dana, 1852 and *Metaconchoecia* Granata and Caporiacco, 1949 (Angel pers. com). However, although there has been a good coverage of both morphological and molecular analysis of halocyprid ostracods from the Atlantic Ocean and the Southern Ocean, there has yet to be a similar coverage of both morphological and molecular analysis of halocyprid ostracods in other oceans.

A pilot study to examine the Gulf of Oman specimens of *Mamilloecia* using SEM techniques was unsuccessful (Graves 2012). Firstly the preservation of the specimens was far from ideal for SEM studies: specific preservation in glutaraldehyde may have yielded better results. However, it was concluded that the general lack of calcification of the halocyprid carapaces was the main factor contributing to the very poor quality of the images, and it was decided that continuing to pursue this approach would not be productive. Certainly, if a future project is designed to study the microstructure of halocyprid carapaces, material should be collected and fixed specifically for this objective.

It was quickly evident that the most abundant halocyprid ostracod taxon found in the Gulf of Oman samples was the genus *Euconchoecia*. Even casual examination of the samples showed there were two size groups present, neither of which could be attributed to the original descriptions of any species in the genus. However, comparisons were problematic because of the inadequacy of these original descriptions (Müller 1890, 1906; Scott 1894). Previous studies of halocyprids in the Indian Ocean (Poulsen 1969, George 1977) had attributed the species to *E. chierchiae* Müller, 1890 and *E. aculeata* Scott, 1894. Both are species that were originally described from the Atlantic, *E. chierchiae* – the type species for the genus – came from Brazilian coastal waters and *E. aculeata* from the Gulf of Guinea. The original type material of the former could not be traced and may have been lost during World War II, but type material of the latter is archived in the Natural History Museum and was re-examined. Critical examination of the Gulf of Oman specimens showed firstly that the two size groups were different species, and that neither species was conspecific with *E. chierchiae* from the Atlantic (whose identity may not be the same as the original species described by Müller (1906), nor with the type specimens of *E. aculeata* (Scott 1894). Hence each of the two size morphs has been described as new species *E. omanensis* Graves, 2011 and *E. hormuzensis* Graves, 2011 respectively. *Euconchoecia* is a genus that occurs abundantly in coastal waters throughout much of the tropical and subtropical IndoPacific and to a lesser extent in the Atlantic. In the IndoPacific tropical seaway fluctuating sea-levels during the Pleistocene glaciations may have resulted in cycles of isolation and recombination that is postulated to have resulted in speciation in other planktonic groups such as Copepoda (Fleminger 1986). *Euconchoecia* is also exceptional amongst halocyprid ostracods, as the females brood their eggs within the carapace and release them at the first instar stage; a reproductive strategy that is the rule elsewhere in the Myodocopida, but not in the Halocyprida. This may result in *Euconchoecia* species having higher reproductive rates and hence can respond more rapidly to the changing conditions resulting from the seasonal monsoons.

Another taxonomic issue arose when a species in the deeper Gulf of Oman samples was found to be superficially very similar to *Paraconchoecia mamillata* Müller, 1906, an Atlantic Ocean species. Once again morphological and statistical analyses, and comparisons with the material in the Natural History Museum collections from the Atlantic, showed that the Gulf of Oman species differs significantly from the Atlantic species and was novel. Furthermore the external morphology of these two species differ considerably from that of the type species of *Paraconchoecia*, *P. spinifera*, and detailed comparisons between them and *P. spinifera* confirmed they do not belong to the same genus. So a new genus *Mamilloecia* Graves, 2012 was established to contain these two species (and a third species, formerly *P. nanomamillata,* Deevey and Brooks, (1980)) with the novel Gulf of Oman species *Mamilloecia indica* Graves, 2012 being designated the type species (Graves 2012). It is evident that despite the splitting off of the *Mamilloecia* species, *Paraconchoecia* is still a polyphyletic taxon and requires further subdivision.

There had been no previous deep water sampling in the Gulf of Oman and the deep water samples from 1800 – 2000 m contained several specimens of a species that superficially appeared to be a *Conchoecia* Dana, 1849 species, but on further examination proved to be a member of a new genus. These specimens have been named as *Huxleyoecia muscatensis* nov.gen. nov.sp. (see Chapter 4). At present the new genus is monotypic, but it seems probable that when further deep sampling is conducted at similar depths throughout the IndoPacific, additional species will be found.

One of the deep water samples from 2000 m contained specimens of the poorly known species *Mollicia minki* Poulsen, 1973. These are the only specimens found since the original description. While researching this genus, an interesting nomenclatural problem was revealed: the generic name *Mollicia* proposed by Poulsen (1973) is preoccupied by a genus of jumping spider, *Mollicia* Marples, 1964. The name as applied to the spider, *Mollicia* Marples, 1964, has precedence. Hence the new name of *Mollicoecia* is proposed for all the ostracod species currently classified in the genus (see Chapter 5). In addition the specimens of *M. minki* in the Gulf of Oman deep water samples are redescribed according to modern criteria.

7.3 Bathymetric Distribution

In 1995 a series of research cruises under the aegis of the US Joint Global Ocean Flux study (JGOFS) was undertaken to study the bathymetric distribution of mesozooplankton in the Arabian Sea during the southwest and northeast monsoon. The results for the halocyprids from these studies are yet to be published (Drapun, pers com.). However, no plankton sampling was conducted in the Gulf of Oman, and the sampling was limited to depths <1500m and so will barely have extended below the influence of the zone of low oxygen.

These samples from the Gulf of Oman collected during the northeast monsoon of 1997, and systematically sampled to depths of 2000m provide a unique insight into the factors influencing the bathymetric distributions of the halocyprids. Similar studies in the Atlantic (Angel et al. 2007) showed that salinity and temperature do not have a direct effect on halocyprid abundances, and the same was demonstrated here for the Gulf of

Oman data. However, it is clear that in the Gulf of Oman the presence of the deep oxygen minimum zone does have a profound effect on ostracod abundances. The maximum abundances of ostracods were in the 150 – 100 m samples. The abundances of several species were reduced to single specimens at 700 – 600 m where oxygen concentrations were < 2 ml/l. Their abundances increased again below 1400 m, as the influence of the factors resulting in the intense oxygen minimum waned and the deep northward spread of well oxygenated water masses from the more southerly latitudes raised the availability of *in situ* dissolved oxygen.

Comparisons between the Atlantic data (Angel 1979) and the Gulf of Oman data show that the numbers of species and the extent of their diurnal vertical migrations were far lower in the Gulf of Oman than at comparable latitudes in the Atlantic. This is almost certainly the result of the influence of the intense oxygen minimum not only on the halocyprids, but also on the micronekton species (fish, decapods and amphipods) that are their main predators (Herring et al. 1999).

7.4 Species Composition

Poulsen (1977) reported that where oxygen concentrations fell to < 1 ml/l in the Indian Ocean, there was a sharp decline in ostracod abundance an observation with which the data from the Gulf of Oman agree. Furthermore throughout the water column in the Gulf of Oman species richness is much lower than at comparable latitudes in the Atlantic Ocean. Angel (1979) identified 65 species in the upper 2000m at Station 7856 at 30ºN 23°W in the Atlantic Ocean which is much higher than the 37 species identified in the Gulf of Oman samples. Moreover, there is a largely unexplained disparity in the number of ostracod species collected in the day and night series of samples; the night samples were consistently richer in species than the day samples. So could net avoidance be an important factor? The halocyprids do not possess image forming eyes, so can not detect visual cues. Furthermore the surface waters were highly productive, and although no light measurements were made, it is probable that the nets could not have been detected visually by day at depths in excess of 500 m. The abundances of micronektonic species were not high enough for bioluminescence in the net to serve as a sufficient deterrent. In the Atlantic samples reported by Angel et al (2007) there was no similar disparity in species richness between the day and night samples. Another possible explanation is that because the nets were operated by different teams by day and by night, the way the nets were handled at night may have resulted in greater leakage of surface species into the deeper nets. Inevitably the nets are held near the surface for a short time during their retrieval when the pitching of the ship may increase the amount of contamination of deeper samples with surface species However, in the Gulf of Oman the deep water sampling from 1400 – 2000 m was carried out only at night and species richness increased considerably below 1400 m (see Chapter 6).

7.5 Summary

The high numbers of novel taxa described from the Gulf, which superficially resemble known taxa, challenges the concept that many halocyprid species have cosmopolitan distributions throughout the world's oceans (Poulsen 1977). Detailed morphological and meristic analyses have uncovered unexpected diversity in the halocyprid species, and the implication is that there are many more cryptic species to be discovered. It appears that the present global inventory of some 200 halocyprid species may be a substantial underestimate.

The collection of repeat series of samples at the same position with the same equipment, could make a significant contribution to ascertaining how environmental changes both short term, resulting from the monsoon cycle, and long term, resulting from climate change, are impacting pelagic community structure and functioning in general, by causing changes in ostracod abundances and distributions. Regrettably, the political situation in the area makes any repeat of this research most unlikely for the foreseeable future. However, the intensive effort required to conduct this sort of classical approach to zooplankton ecology, which investigates species in detail and not just processes, or proxies (such as particle counters) or indicators (such as acoustic back-scatter) will always be rewarding, but is highly reliant on well archived collections and on the experience of classical taxonomists.

7.6 References

Angel, M.V. 1979. Studies on Atlantic halocyprid ostracods: their vertical distributions and community structure in the central gyre region along latitude 30°N from off Africa to Bermuda. Progress in Oceanography, 8, 1-122.

Angel M.V. (1984). The diurnal migrations and distributions of a mesopelagic community in the North-east Atlantic. 3. Planktonic ostracods, a stable component in the community. Progress in Oceanography, 13, 319-351.

Angel MV. 2010. Towards a full inventory of planktonic Ostracoda (Crustacea) for the subtropical Northwestern Atlantic Ocean. Deep Sea Research II, 57, 24-26, 2173-2188.

Angel MV. Blachowiak-Samolyk K. Drapun I. Castillo R. 2007. Changes in the composition of planktonic ostracod populations across a range of latitudes in the North-east Atlantic. Progress in Oceanography, 73, 1, 60-78.

Angel M.V. Hargreaves P. Kirkpatrick P. Domanski P. (1982). Low variability in planktonic and micronektonic populations at 1000m depth in the vicinity of 42°N 17°W; evidence against diel migratory behaviour in the majority of species. Biological Oceanography, 1, 287-319.

Brady G.S. 1880. Report on the Ostracoda dredged by H.M.S. Challenger during the years 1873-1876. Scientific Results of the Voyages of H.M.S. Challenger (Zoology). 1, (3), 1-184.

Claus C. 1891. Die Halocypriden des Atlantischen Oceans und Mittelmeeres. Alfred Hölder, Wien, 1-81.

Dana J.D. 1849. Conspectus Crustaceorum quae Orbis Terrarum circumnavigatione, Carolo Wilkes e Classe Republicae Foederatae Duce, lexit et descripsit J.D.Dana. Proceedings of the American Academy of Arts and Sciences, 2, 9061.

Dana J.D. 1852. Crustacea. Part II. In: United States Exploring Expedition During the Years 1838, 1839, 1840, 1841, 1842 Under the Command of Charles Wilkes, U.S.N., 13, 2, 689-1618.

Fleminger A. 1986. The Pleistocene equatorial barrier between the Indian and Pacific Oceans and a likely cause for Wallace's line. UNESCO Technical Papers in Marine Science, 49, 84-97.

George J. 1977. Studies on planktonic ostracods of the Northern Indian Ocean. PhD. Thesis, University of Cochin.

Granata L. Caporiacco L. 1949. Ostracods marins recuellis pendant les croissières du Prince Albert 1 er de Monaco. Resultats des campagnes, Scientific Prince Albert 1 er, 109, 1-51.

Graves C. 2011. Redescription of *Euconchoecia chierchiae* Müller, 1890 and *Euconchoecia aculeata* (Scott, 1894) (Halocyprididae, Ostracoda) from the Atlantic, and Descriptions of Two Novel Species of *Euconchoecia* Müller 1890, from the Gulf of Oman. Journal of Natural History, 45, 29-32, 1937-1981.

Graves C. 2012. *Mamilloecia indica* (Halocyprididae:Ostracoda) a new genus and species from the Northwest Indian Ocean, Journal of Natural History, 46, 9-10, 516-556.

Herring PJ. Howell PR. Pugh PR. 1999. Scheherezade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb – 30 Apr 1997. No 16, Fish, decapod shrimps and siphonophores: abundances and size data. Leg1. 12 Feb – Mar 1997 (Unpublished manuscript).

Marples BJ. 1964. Spiders from some Pacific Islands. Part IV. The Cook Islands and Niue. Pacific Science, 14, 382-388.

Müller, G.W. 1890. Ueber Halocypriden. Zoologische Jahrbücher, 5, 253-280.

Müller, G.W. 1906. Ostracoda. Wissenschaftliche Ergebnisse der Deutschen Tiefsee-Expedition 'Valdivia' 1989-1899. 8, 29-154.

Poulsen EM. 1969. Ostracoda-Myodocopa. 3a. Halocypriformes-Thaumatocypridae and Halocypridae. Dana Report, 75, 1–100.

Poulsen E.M. 1973. Ostracoda-Myodocopa. 3b. Halocypriformes-Halocypridae. Conchoecinae. Dana Report, 84, 1-223.

Poulsen EM. 1977 Zoogeographical remarks on marine pelagic ostracoda. Dana Report, 87, 1-34.

Scott T. 1894. Report on Entomostraca from the Gulf of Guinea collected by John Rattray BSc. Transactions of the Linnean Society, London, Series 2, 6, 1-16.

Wiebe PH. Bucklin A. Madin L. Angel MV. Sutton T. Pagés F. Hopcroft RR.Lindsay D. 2010. Deep-sea sampling on CMarZ cruises in the Atlantic Ocean – An introduction. Deep Sea Research II, 57, 24-26, 2157-2166.

Acknowledgements

I am very grateful to Dr Martin Angel of the National Oceanography Centre and Professor Geoff Boxshall for all their help and support. The staff at the Natural History Museum, London for providing the material and facilities. I especially thank my husband Raymond and my daughter Helen for their continual encouragement.

Appendices

Appendix 1. Length measurements of *Euconchoecia chierchiae* females.

specimen	length (mm)
1	1.22
2	1.28
3	1.22
4	1.24
5	1.18
6	1.22
7	1.24
8	1.28
9	1.24
10	1.24
11	1.20
12	1.18
13	1.18
14	1.16
15	1.32
16	1.26
17	1.18
18	1.26
19	1.28
20	1.24
21	1.26
22	1.18
23	1.22
24	1.32
25	1.34
26	1.24
27	1.20
28	1.18
29	1.22
30	1.24
31	1.30
32	1.26
Mean	1.24
SD±	0.05
minimum	1.16
maximum	1.34

Appendix 2. Length measurements of *Euconchoecia chierchiae* males.

specimen	length (mm)
1	1.24
2	1.12
3	1.16
4	1.28
5	1.28
6	1.28
7	1.24
8	1.24
9	1.28
Mean	1.24
SD±	0.06
minimum	1.12
maximum	1.28

Appendix 3. Length measurements of *Euconchoecia hormuzensis* females.

specimen	length (mm)
1	1.12
2	1.10
3	0.94
4	1.14
5	1.04
6	1.04
7	1.00
8	0.98
9	0.98
10	1.04
11	1.10
12	1.00
13	1.04
14	1.04
15	1.04
16	1.08
17	0.98
18	1.04
19	1.06
20	1.06
21	1.00
22	1.00
23	1.08
24	0.96
25	1.02
26	1.08
27	1.02
28	1.14
29	1.12
30	1.04
31	1.00
32	1.00
33	1.00
34	1.04
35	1.04
36	1.08
37	1.04
38	1.04
39	1.14
40	1.06
41	0.96
42	1.02
43	0.98
44	1.02
45	1.10
46	1.04
47	1.04
48	1.16
Mean	1.04
SD±	0.05
minimum	0.94
maximum	1.16

Appendix 4. Length measurements of *Euconchoecia hormuzensis* males.

specimen	length (mm)
1	1.00
2	1.00
3	1.02
4	1.04
5	1.04
6	0.98
7	1.04
8	1.04
9	1.00
10	1.04
11	1.00
12	1.02
13	0.98
14	1.00
15	0.96
16	0.98
17	0.98
18	1.00
19	0.98
20	0.98
21	1.02
22	1.00
23	1.02
24	0.98
25	0.94
26	0.96
27	0.98
28	1.04
29	1.00
30	1.00
31	1.00
32	1.00
33	1.04
34	0.96
35	0.90
36	1.02
Mean	1.00
SD±	0.03
minimum	0.90
maximum	1.04

Appendix 5. Length measurements of *Euconchoecia omanensis* females.

specimen	length (mm)	specimen	length (mm)
1	1.34	51	1.46
2	1.38	52	1.56
3	1.44	53	1.44
4	1.46	54	1.46
5	1.38	55	1.48
6	1.36	56	1.38
7	1.52	57	1.44
8	1.34	58	1.44
9	1.38	59	1.48
10	1.40	60	1.38
11	1.36	61	1.38
12	1.36	62	1.50
13	1.36	63	1.46
14	1.56	64	1.40
15	1.32	65	1.54
16	1.36	66	1.42
17	1.34	67	1.30
18	1.44	68	1.40
19	1.36	69	1.44
20	1.34	70	1.30
21	1.38	71	1.38
22	1.36	72	1.40
23	1.40	73	1.42
24	1.44	74	1.42
25	1.36	75	1.46
26	1.46	76	1.44
27	1.44	77	1.48
28	1.44	78	1.36
29	1.34	79	1.54
30	1.28	80	1.50
31	1.38	81	1.50
32	1.40	82	1.46
33	1.48	83	1.48
34	1.34	84	1.40
35	1.40	85	1.50
36	1.54	86	1.40
37	1.40	87	1.40
38	1.38	88	1.38
39	1.36	89	1.38
40	1.46	90	1.38
41	1.50	91	1.42
42	1.40	92	1.34
43	1.32	93	1.40
44	1.40	94	1.36
45	1.54	95	1.46
46	1.36	96	1.50
47	1.42	97	1.44
48	1.36	98	1.40
49	1.40	99	1.44
50	1.52	100	1.50

Mean	1.42
SD±	0.06
minimum	1.28
maximum	1.56

Appendix 6. Length measurements of *Euconchoecia omanensis* males.

specimen	length (mm)	specimen	length (mm)
1	1.10	51	1.06
2	1.08	52	1.14
3	1.10	53	1.20
4	1.22	54	1.10
5	1.10	55	1.12
6	1.16	56	1.18
7	1.18	57	1.18
8	1.20	58	1.20
9	1.14	59	1.12
10	1.14	60	1.12
11	1.16	61	1.20
12	1.18	62	1.08
13	1.14	63	1.24
14	1.12	64	1.16
15	1.12	65	1.16
16	1.10	66	1.12
17	1.18	67	1.14
18	1.14	68	1.14
19	1.18	69	1.14
20	1.16	70	1.20
21	1.12	71	1.24
22	1.14	72	1.16
23	1.16	73	1.18
24	1.16	74	1.12
25	1.10	75	1.18
26	1.10	76	1.24
27	1.14	77	1.22
28	1.14	78	1.18
29	1.14	79	1.16
30	1.08	80	1.16
31	1.18	81	1.10
32	1.06	82	1.10
33	1.20	83	1.14
34	1.18	84	1.14
35	1.16	85	1.10
36	1.18	86	1.16
37	1.16	87	1.14
38	1.10	88	1.12
39	1.12	89	1.16
40	1.18	90	1.18
41	1.16	91	1.08
42	1.12	92	1.16
43	1.32	93	1.08
44	1.16	94	1.08
45	1.14	95	1.14
46	1.20	96	1.16
47	1.10	97	1.16
48	1.14	98	1.14
49	1.06	99	1.12
50	1.20	100	1.16

Mean	1.15
SD±	0.04
minimum	1.06
maximum	1.32

Appendix 7. Length measurements of *Huxleyoecia muscatensis* females.

specimen	length (mm)
1	1.98
2	1.98
3	1.96
4	2.02
5	1.94
6	1.96
7	2.02
8	1.96
9	2.02
10	1.92
11	1.98
12	1.96
13	1.96
14	2.04
15	1.96
16	1.90
17	1.92
18	1.94
19	1.96
20	1.94
21	1.94
22	1.96
23	2.00
24	1.94
25	1.96
26	1.96
27	2.04
28	1.94
29	1.98
30	1.92
31	1.94
32	1.98
33	1.90
34	1.96
35	1.88
36	1.90
37	1.98
38	1.90
Mean	1.96
SD±	0.04
minimum	1.88
maximum	2.04

Appendix 8. Length measurements of *Huxleyoecia muscatensis* males.

specimen	length (mm)
1	1.68
2	1.72
3	1.78
4	1.80
5	1.74
6	1.80
7	1.74
8	1.74
9	1.80
10	1.74
11	1.68
12	1.72
Mean	1.75
SD±	0.04
minimum	1.68
maximum	1.80

Appendix 9. Length measurements of *Mamilloecia indica* females.

specimen	length (mm)	specimen	length (mm)
1	1.92	51	1.86
2	1.86	52	1.86
3	1.86	53	1.88
4	1.86	54	1.90
5	1.88	55	1.90
6	1.80	56	1.86
7	1.86	57	1.84
8	1.88	58	1.92
9	1.90	59	1.86
10	1.86	60	1.84
11	1.88	61	1.82
12	1.88	62	1.82
13	1.90	63	1.86
14	1.94	64	1.86
15	1.86	65	1.94
16	1.86	66	1.86
17	1.90	67	1.90
18	1.84	68	1.84
19	1.82	69	1.86
20	1.90	70	1.86
21	1.78	71	1.86
22	1.82	72	1.92
23	1.90	73	1.92
24	1.90	74	1.90
25	1.86	75	1.94
26	1.84	76	1.94
27	1.86	77	1.86
28	1.94	78	1.88
29	1.90	79	1.88
30	1.84	80	1.90
31	1.86	81	1.92
32	1.84	82	1.84
33	1.88	83	1.84
34	1.88	84	1.90
35	1.88	85	1.94
36	1.84	86	1.84
37	1.90	87	1.88
38	1.94	88	1.80
39	1.84	89	1.90
40	1.88	90	1.94
41	1.88	91	1.86
42	1.82	92	1.88
43	1.94	93	1.88
44	1.90	94	1.88
45	1.88	95	1.86
46	1.90	96	1.88
47	1.92	97	1.82
48	1.88	98	1.92
49	1.94	99	1.90
50	1.92	100	1.94

Mean	1.88
SD±	0.04
minimum	1.78
maximum	1.94

Appendix 10. Length measurements of *Mamilloecia indica* males.

specimen	length (mm)	specimen	length (mm)
1	1.64	51	1.68
2	1.58	52	1.60
3	1.64	53	1.56
4	1.64	54	1.66
5	1.60	55	1.56
6	1.64	56	1.64
7	1.64	57	1.66
8	1.60	58	1.58
9	1.60	59	1.64
10	1.58	60	1.70
11	1.66	61	1.72
12	1.68	62	1.68
13	1.64	63	1.66
14	1.64	64	1.64
15	1.60	65	1.56
16	1.64	66	1.64
17	1.64	67	1.56
18	1.66	68	1.68
19	1.66	69	1.64
20	1.70	70	1.64
21	1.64	71	1.62
22	1.64	72	1.56
23	1.56	73	1.66
24	1.60	74	1.64
25	1.66	75	1.62
26	1.68	76	1.64
27	1.64	77	1.68
28	1.64	78	1.64
29	1.58	79	1.66
30	1.56	80	1.68
31	1.60	81	1.64
32	1.64	82	1.64
33	1.66	83	1.60
34	1.60	84	1.66
35	1.62	85	1.66
36	1.68	86	1.66
37	1.54	87	1.64
38	1.60	88	1.64
39	1.54	89	1.70
40	1.64	90	1.66
41	1.62	91	1.68
42	1.62	92	1.60
43	1.60	93	1.60
44	1.58	94	1.56
45	1.62	95	1.60
46	1.66	96	1.64
47	1.68	97	1.58
48	1.62	98	1.64
49	1.66	99	1.64
50	1.66	100	1.60

Mean	1.63
SD±	0.04
minimum	1.54
maximum	1.72

Appendix 11. Length measurements of *Mamilloecia mamillata* females.

specimen	length (mm)
1	1.78
2	1.76
3	1.74
4	1.74
5	1.74
6	1.78
7	1.84
8	1.74
9	1.76
10	1.76
11	1.76
12	1.74
13	1.80
14	1.72
15	1.76
16	1.70
17	1.70
18	1.74
19	1.74
20	1.74
21	1.72
22	1.70
23	1.76
24	1.74
25	1.74
26	1.70
27	1.80
28	1.74
29	1.72
30	1.78
31	1.70
32	1.74
33	1.72
34	1.70
35	1.76
36	1.74
37	1.76
38	1.74
39	1.74
40	1.76
41	1.78
42	1.78
43	1.74
44	1.76
45	1.68
46	1.76
47	1.76
48	1.74
49	1.74
50	1.78
51	1.74
52	1.72
53	1.76
Mean	1.75
SD±	0.03
minimum	1.68
maximum	1.84

Appendix 12. Length measurements of *Mamilloecia mamillata* males.

specimen	length (mm)
1	1.72
2	1.72
3	1.72
4	1.70
5	1.72
6	1.80
7	1.66
8	1.72
9	1.68
10	1.72
11	1.74
12	1.72
13	1.66
14	1.76
15	1.68
16	1.74
17	1.66
18	1.66
19	1.66
20	1.60
21	1.64
22	1.66
23	1.68
24	1.68
25	1.72
26	1.64
27	1.70
28	1.70
29	1.64
30	1.66
31	1.66
32	1.74
33	1.74
Mean	1.69
SD±	0.04
minimum	1.60
maximum	1.80

Appendix 13. Length measurements of *Mollicoecia minki* females.

specimen	length (mm)
1	3.28
2	3.36
3	3.28
Mean	3.31
SD±	0.05
minimum	3.28
maximum	3.36

Appendix 14. Length measurements of *Mollicoecia minki* males.

specimen	length (mm)
1	3.00
2	2.96
3	3.00
4	2.96
5	2.96
Mean	2.98
SD±	0.02
minimum	2.96
maximum	3.00

Appendix 15. Length measurements of *Paraconchoecia spinifera* females.

specimen	length (mm)	specimen	length (mm)
1	2.12	51	2.12
2	2.14	52	2.14
3	2.14	53	2.16
4	2.16	54	2.14
5	2.10	55	2.08
6	2.04	56	2.16
7	2.16	57	2.16
8	2.10	58	2.10
9	2.12	59	2.14
10	2.14	60	2.16
11	2.18	61	2.16
12	2.14	62	2.12
13	2.10	63	2.16
14	2.10	64	2.08
15	2.12	65	2.12
16	2.12	66	2.14
17	2.08	67	2.14
18	2.08	68	2.10
19	2.08	69	2.16
20	2.14	70	2.14
21	2.16	71	2.16
22	2.14	72	2.16
23	2.14	73	2.10
24	2.10	74	2.12
25	2.10	75	2.20
26	2.14	76	2.08
27	2.10	77	2.12
28	2.14	78	2.16
29	2.12	79	2.10
30	2.16	80	2.16
31	2.10	81	2.10
32	2.16	82	2.14
33	2.10	83	2.06
34	2.14	84	2.16
35	2.10	85	2.10
36	2.16	86	2.14
37	2.16	87	2.04
38	2.14	88	2.12
39	2.14	89	2.16
40	2.16	90	2.14
41	2.10	91	2.16
42	2.14	92	2.08
43	2.12	93	2.04
44	2.08	94	2.06
45	2.08	95	2.10
46	2.08	96	2.14
47	2.10	97	2.12
48	2.10	98	2.14
49	2.16	99	2.16
50	2.14	100	2.12

Mean	2.12
SD±	0.03
minimum	2.04
maximum	2.20

Appendix 16. Length measurements of *Paraconchoecia spinifera* males.

specimen	length (mm)	specimen	length (mm)
1	1.82	51	1.74
2	1.80	52	1.80
3	1.76	53	1.74
4	1.76	54	1.76
5	1.78	55	1.76
6	1.74	56	1.72
7	1.76	57	1.74
8	1.80	58	1.78
9	1.84	59	1.68
10	1.78	60	1.70
11	1.76	61	1.70
12	1.78	62	1.74
13	1.72	63	1.76
14	1.78	64	1.76
15	1.84	65	1.76
16	1.78	66	1.76
17	1.78	67	1.74
18	1.78	68	1.74
19	1.76	69	1.74
20	1.80	70	1.74
21	1.78	71	1.70
22	1.74	72	1.72
23	1.74	73	1.74
24	1.86	74	1.72
25	1.76	75	1.78
26	1.80	76	1.70
27	1.76	77	1.76
28	1.76	78	1.74
29	1.78	79	1.72
30	1.76	80	1.72
31	1.82	81	1.74
32	1.78	82	1.74
33	1.82	83	1.76
34	1.74	84	1.76
35	1.78	85	1.74
36	1.76	86	1.76
37	1.78	87	1.76
38	1.80	88	1.68
39	1.80	89	1.80
40	1.78	90	1.84
41	1.76	91	1.78
42	1.84	92	1.78
43	1.80	93	1.80
44	1.74	94	1.76
45	1.78	95	1.74
46	1.74	96	1.82
47	1.84	97	1.82
48	1.76	98	1.80
49	1.82	99	1.80
50	1.74	100	1.74

Mean	1.77
SD±	0.04
minimum	1.68
maximum	1.86

Appendix 17 Halocyprid ostracod totals and CTD data

RMT1 Trawls														CTD Data										
Station	Day or Night	Depth Range m	Sample volume m^3	Ostracoda					Depth m				Data Points in Depth Range	Ptemp ^oC			Salinity psu			Oxygen ml/l		
				Fraction	Fraction Total	Sample Total	per $1000m^3$	$Log_e(N+1)$	Min	Max	Mean	Range		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
54001#27	Day	0 - 50	1279	50.0%	1345	2690	2103	7.652	0	50	25	50	13	22.95	24.37	23.14	36.47	36.50	36.48	188.3	212.8	204.4
54001#26	Day	50 - 100	1172	25.0%	2244	8976	7659	8.944	50	100	75	50	13	20.11	22.95	21.89	36.02	36.47	36.29	6.4	195.8	117.3
54001#25	Day	100 - 150	1276	12.5%	1689	13512	10589	9.268	100	150	125	50	13	18.92	19.99	19.43	36.01	36.08	36.03	2.4	4.7	3.3
54001#03	Day	150 - 200	2589	100.0%	12608	12608	4870	8.491	150	200	175	50	13	17.96	18.92	18.45	36.06	36.16	36.11	2.4	2.7	2.5
54001#02	Day	200 - 300	2306	100.0%	1026	1026	445	6.100	200	300	250	100	25	16.24	17.95	17.04	36.19	36.28	36.23	2.5	3.3	2.8
54001#01	Day	300 - 400	2449	100.0%	101	101	41	3.743	300	400	350	100	25	14.42	16.25	15.27	36.04	36.29	36.16	1.7	4.0	2.7
54001#15	Day	394 - 504	2665	100.0%	13	13	5	1.771	394	504	449	110	28	12.82	14.47	13.61	35.80	36.05	35.92	1.3	1.9	1.5
54001#14	Day	504 - 605	2549	100.0%	13	13	5	1.808	504	605	554.5	101	24	11.92	12.79	12.33	35.70	35.79	35.74	1.5	2.4	1.9
54001#13	Day	600 - 700	2486	100.0%	2	2	1	0.590	600	700	650	100	25	11.18	11.92	11.53	35.63	35.70	35.66	2.3	4.2	3.1
54001#12	Day	695 - 800	2589	100.0%	6	6	2	1.199	695	800	747.5	105	26	10.37	11.18	10.78	35.57	35.63	35.60	4.2	5.9	5.2
54001#11	Day	800 - 896	2325	100.0%	9	9	4	1.583	800	896	848	96	24	9.74	10.33	10.05	35.52	35.56	35.54	6.0	7.1	6.5
54001#10	Day	896 - 1000	2389	100.0%	95	95	40	3.708	896	1000	948	104	26	8.93	9.70	9.28	35.43	35.51	35.47	7.2	8.1	7.6
54001#24	Day	1007 - 1100	2614	100.0%	231	231	88	4.493	1007	1100	1053.5	93	23	8.15	8.83	8.49	35.35	35.42	35.39	8.1	9.6	8.9
54001#23	Day	1100 - 1190	2343	100.0%	79	79	34	3.547	1100	1190	1145	90	23	7.34	8.11	7.70	35.26	35.35	35.30	9.7	12.6	11.4
54001#22	Day	1195 - 1415	4818	100.0%	84	84	17	2.914	1195	1415	1305	220	55	5.86	7.29	6.58	35.11	35.26	35.18	13.1	28.2	19.6
54001#21	Night	0 - 50	2574	50.0%	3868	7736	3005	8.009	0	50	25	50	13	22.95	24.37	23.14	36.47	36.50	36.48	188.3	212.8	204.4
54001#20	Night	50 - 100	2307	25.0%	5563	22252	9645	9.174	50	100	75	50	13	20.11	22.95	21.89	36.02	36.47	36.29	6.4	195.8	117.3
54001#19	Night	100 - 157	2575	100.0%	19425	19425	7544	8.929	100	157	128.5	57	14	18.85	19.99	19.39	36.01	36.09	36.04	2.4	4.7	3.2
54001#06	Night	152 - 201	2746	100.0%	6831	6831	2488	7.819	152	201	176.5	49	12	17.96	18.85	18.41	36.06	36.16	36.11	2.4	2.7	2.5
54001#05	Night	201 - 305	2511	100.0%	23	23	9	2.318	201	305	253	104	26	16.24	17.95	17.01	36.19	36.28	36.24	2.5	3.5	2.8
54001#04	Night	305 - 400	2647	100.0%	371	371	140	4.950	305	400	352.5	95	24	14.42	16.07	15.23	36.04	36.29	36.15	1.7	4.0	2.7
54001#18	Night	403 - 497	2704	100.0%	3	3	1	0.746	403	497	450	94	23	12.94	14.25	13.57	35.81	36.02	35.91	1.3	1.8	1.5
54001#17	Night	497 - 598	2525	100.0%	3	3	1	0.783	497	598	547.5	101	25	11.96	12.89	12.39	35.70	35.81	35.75	1.5	2.3	1.8
54001#16	Night	598 - 694	2644	100.0%	2	2	1	0.563	598	694	646	96	25	11.21	11.96	11.56	35.64	35.70	35.67	2.3	3.9	3.0
54001#09	Night	699 - 800	2654	100.0%	74	74	28	3.363	699	800	749.5	101	25	10.37	11.14	10.76	35.57	35.63	35.60	4.2	5.9	5.2
54001#08	Night	800 - 894	2378	100.0%	43	43	18	2.949	800	894	847	94	24	9.74	10.33	10.05	35.52	35.56	35.54	6.0	7.1	6.5
54001#07	Night	894 - 1016	2468	100.0%	29	29	12	2.546	894	1016	955	122	31	8.79	9.74	9.24	35.42	35.52	35.46	7.1	8.2	7.6
54001#31	Night	1387 - 1600	5117	100.0%	1706	1706	333	5.812	1387	1600	1493.5	213	53	4.80	6.04	5.41	35.01	35.13	35.07	25.9	45.2	35.5
54001#30	Night	1600 - 1833	4973	100.0%	1123	1123	226	5.424	1600	1833	1716.5	233	58	3.60	4.75	4.13	34.90	35.01	34.95	45.9	69.9	58.8
54001#29	Night	1821 - 2009	5253	100.0%	697	697	133	4.895	1821	2009	1915	188	47	2.96	3.64	3.31	34.85	34.90	34.88	69.4	85.4	76.7

Appendix 18. Total list of species identified from the Gulf of Oman samples.

Alacia alata Müller, 1906
Archiconchoecia striata Müller, 1894
Archiconchoecissa cucullata Brady, 1902
Bathyconchoecia georgi Angel, pers. com.
Bathyconchoecia sp.
Conchoecetta giesbrechti Müller, 1906
Conchoecia decipiens Müller, 1906
Conchoecia hyalophyllum Claus, 1890
Conchoecissa plinthina Müller, 1906
Conchoecissa symmetrica Müller, 1906
Discoconchoecia elegans Sars, 1866
Euconchoecia hormuzensis Graves, 2011
Euconchoecia omanensis Graves, 2011
Felia dispar Deevey, 1982
Gaussica subedentata Gooday, 1976
Halocypris striata Chavtur, 1977
Huxleyoecia muscatensis (Chapter 4)
Loricia ctenophora Müller, 1906
Mamilloecia indica Graves, 2012
Metaconchoecia acuta Gooday, 1981
Metaconchoecia arcuata Deevey, 1978
Metaconchoecia glandulosa Müller, 1906
Metaconchoecia inflata Gooday, 1981
Metaconchoecia macromma Müller, 1906
Metaconchoecia pusilla Müller, 1906
Metaconchoecia subinflata Gooday, 1981
Mikroconchoecia stigmatica Müller, 1906
Mollicoecia minki (Chapter 5)
Orthoconchoecia atlantica Lubbock, 1856
Paraconchoecia cophopyga Müller, 1906
Paraconchoecia macroreticulata Ellis, 1984
Paraconchoecia oblonga Claus, 1890
Paramollicia dichotoma Müller, 1906
Paramollicia distans Müller, 1906
Porrecia parthenoda Müller, 1906
Porrecia porrecta Claus, 1890
Proceroecia brachyaskos Müller, 1906
Proceroecia procera Müller, 1894
Pseudoconchoecia concentrica Müller, 1906

Journal of Natural History
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713192031

Redescription of *Euconchoecia chierchiae* Müller, 1890 and *Euconchoecia aculeata* (Scott, 1894) (Halocyprididae: Ostracoda) from the Atlantic, and descriptions of two novel species of *Euconchoecia* Müller 1890, from the Gulf of Oman

Carol Graves[a]
[a] Zoology Department, Natural History Museum, London, UK

Online publication date: 08 June 2011

To cite this Article Graves, Carol(2011) 'Redescription of *Euconchoecia chierchiae* Müller, 1890 and *Euconchoecia aculeata* (Scott, 1894) (Halocyprididae: Ostracoda) from the Atlantic, and descriptions of two novel species of *Euconchoecia* Müller 1890, from the Gulf of Oman', Journal of Natural History, 45: 31, 1937 — 1981

To link to this Article: DOI: 10.1080/00222933.2011.573100

URL: http://dx.doi.org/10.1080/00222933.2011.573100

Journal of Natural History
Vol. 45, Nos. 31–32, August 2011, 1937–1981

Redescription of *Euconchoecia chierchiae* Müller, 1890 and *Euconchoecia aculeata* (Scott, 1894) (Halocyprididae: Ostracoda) from the Atlantic, and descriptions of two novel species of *Euconchoecia* Müller 1890, from the Gulf of Oman

Carol Graves*

Zoology Department, Natural History Museum, London, SW7 5BD UK

(Received 7 October 2010; final version received 13 March 2011; printed 3 June 2011)

The 100–0 m samples from a stratified zooplankton sample series from the upwelling region of the Gulf of Oman, during February 1997, were numerically dominated by members of the poorly known halocyprid genus *Euconchoecia*. A modern diagnosis of the genus *Euconchoecia* is provided and the type species, *Euconchoecia chierchiae* from the Atlantic is redescribed. A second species from the Atlantic, *Euconchoecia aculeata* is also redescribed. In the Gulf of Oman samples there are two size groups, and these were previously identified as *E. chierchiae* and *E. aculeata*. However, when compared with specimens from the Atlantic and with published descriptions of these two species, the Gulf of Oman specimens could not be assigned to any previously described species. In this paper the Gulf of Oman species are described as new species, *Euconchoecia omanensis* and *Euconchoecia hormuzensis*, and are compared in detail with the redescriptions of the Atlantic species, *E. chierchiae and E. aculeata*.

Keywords: ostracods; Myodocopida; plankton; epipelagic; Indian Ocean; oceanic; taxonomy

Introduction

When analysing *Discovery* station 54001, at 24°12′ N, 58°40′ E, a series of stratified zooplankton samples from the upwelling region of the Gulf of Oman, the 100–0 m samples were found to be numerically dominated by members of the poorly known halocyprid genus *Euconchoecia*, together with a species of the myodocopid genus *Cypridina* Edwards, 1840. The genus *Euconchoecia* is exceptional among halocyprid ostracods in that the females retain their eggs in a brood pouch within the carapace, releasing them at the first juvenile instar stage. There are two size groups in the Gulf of Oman samples, and these were previously identified as *Euconchoecia chierchiae* and *Euconchoecia aculeata* by George (1977). However, when compared with material from the Atlantic and with published descriptions of these two named species, the Gulf of Oman specimens could not be assigned to either. In this paper the two Atlantic species are fully redescribed: *Euconchoecia chierchiae*, based on material collected off Bermuda at *Discovery* station 8281 in 1973, and *Euconchoecia aculeata*, based on the type material collected during the cruise of the Telegraph Steamer the *Buccaneer* in

*Email: c.graves@nhm.ac.uk

ISSN 0022-2933 print/ISSN 1464-5262 online

DOI: 10.1080/00222933.2011.573100
http://www.informaworld.com

1893. Detailed comparisons were made of the Gulf of Oman specimens with the new descriptions of the Atlantic species. The Gulf material represents two new species, which are also described in detail.

The genus *Euconchoecia* was established by Müller (1890) as a monotypic genus based on males of *E. chierchiae*, the type species, which had been collected in neritic waters off the coast of Brazil. According to Skogsberg (1920), Cleve subsequently collected two more male specimens from the North Atlantic, but identified them as *Paraconchoecia oblonga* (Cleve 1900). As Cleve gave neither a full description nor any figures, this identification is dubious, although both his specimens displayed the spine at the posterior dorsal corner of the carapace that is characteristic of *Euconchoecia*. *Euconchoecia chierchiae* was next reported by Brady (1902) from Cruz Bay, St John, Virgin Islands, but his rather sketchy description differs from a later account by Müller (1906), so doubt also remains as to the correctness of his identification. Müller (1906) described the female and redescribed the male from the Brazilian coast, but by modern standards his description and his illustrations are inadequate. Skogsberg (1920) provided the first detailed description of both sexes, collected from oceanic waters off Brazil. His material came from close to the type locality, but his description and figures deviate from those of Müller (1906). Vavra (1906) also reported *E. chierchiae* from the Atlantic but all his descriptions are poor. Tseng (1969), working on samples from the Taiwan Strait, published the first report of *E. chierchiae* from outside the Atlantic. His descriptions and drawings again deviate significantly from those of Müller (1906). Poulsen (1969) reported both *E. chierchiae* and *E. aculeata* from numerous Dana stations in the Atlantic, Pacific and Indian Oceans and suggested that the first antenna of the male may have seven segments, two more than originally described by Müller (1890, 1906), but the last two segments were often difficult to observe. There has therefore been considerable confusion surrounding the identity of the type species of the genus, *E. chierchiae.*

A number of other species of *Euconchoecia* have been described from Chinese seas, namely *Euconchoecia maimai* (Tseng, 1969), *Euconchoecia shenghwai* (Tseng, 1969), *Euconchoecia elongata* (Tseng, 1969), *Euconchoecia pacifica* (Chavtur, 1976) and *Euconchoecia bifurcata* (Chen and Lin, 1984). Hence, *Euconchoecia* species have been reported from the Atlantic, Pacific and Indian Oceans, but always restricted to tropical and sub-tropical latitudes between 40° N and 40° S, and predominantly in the upper 50 m of the water column. Abundances are greatest "in neritic waters with an oceanic effect" (da Rocha 1983).

Seven species, including the type species *E. chierchiae chierchiae*, Müller 1890, and two subspecies of *Euconchoecia* have been described to date:

Euconchoecia chierchiae chierchiae Müller, 1890

Euconchoecia chierchiae aspicula (Deevey, 1970)

Euconchoecia aculeata (Scott, 1894)

Euconchoecia bifurcata bifurcata Chen & Lin, 1984

Euconchoecia bifurcata pax Kornicker, 1989

Euconchoecia elongata (Müller, 1906)

Euconchoecia maimai Tseng, 1969

Euconchoecia pacifica (Chavtur, 1976)

Euconchoecia shenghwai Tseng, 1969

Chavtur and Stovbun (personal communication) consider that the genus should comprise 16 species, raising *E. chierchiae aspicula* and *E. bifurcata pax* to full specific status, and reorganizing seven additional new species, which may have been misattributed as other known species. All the material cited by these authors was collected from the western coastal waters of the Pacific Ocean and they included *E. chierchiae* in their study of the systematics of the genus *Euconchoecia.*

The second *Euconchoecia* species to be described was *E. aculeata* (Scott, 1894) based on specimens collected from the Gulf of Guinea. Scott (1894) deposited type material in the Natural History Museum, London, attributing his species to the genus *Halocypris* (Dana, 1853), as *Halocypris aculeata*. Müller (1906, 1912) correctly re-assigned it to *Euconchoecia*. Both Poulsen (1969) and Tseng (1969) later reported this species from various locations outside the Atlantic but without re-examining the type material. Scott's original description was far too sketchy to be confident that these later reports were correctly assigned to his species. Both *E. chierchiae* and *E. aculeata* have been reported from the Indian Ocean (George 1977), but based on the illustrations, these identifications are misattributed and one of them was almost certainly one of the two new species described here from the Gulf of Oman.

Materials and methods

The material described in this paper was from three sources:

(1) The Atlantic material of *E. chierchiae* collected in 1973 off Bermuda at *Discovery* Station 8281, 31°55′18″ N, 63°52′0″ W (Angel 1979), using the multiple rectangular midwater trawl net system (RMT1+8) (Roe and Shale 1979; Roe et al. 1980). The zooplankton samples were originally fixed in 5% seawater formalin and after being sorted were transferred to 70% alcohol for storage at the Natural History Museum, London.

(2) The type material from the Atlantic of *E. aculeata* Scott, 1894, was deposited in the Natural History Museum, London by Scott. The material was collected by a naturalist onboard the Telegraph Steamer *Buccaneer* in 1893 at a station position of 0°19′2″ S, 7°19′0″ E. The type specimens, two females, two males and two juveniles, are now preserved in 80% ethyl alcohol.

(3) Zooplankton samples collected in the Gulf of Oman in 1997 during the northeast monsoon (Herring et al. 1998, 1999). Stratified zooplankton samples were collected by day and by night at an oceanic station in the Gulf of Oman (Discovery 54001, 24°12′ N, 58°40′ E) using a multiple rectangular midwater trawl (RMT1+8) (Roe and Shale 1979; Roe et al. 1980). The mesh size of the zooplankton net (RMT1) was 320 μm, so only adults would have been quantitatively sampled. Total zooplankton samples were initially fixed in 5% seawater formalin, and transferred after 24 h into Steedman's preserving fluid (0.5% propylene phenoxetol, 4.5% propylene glycol, 5% formalin seawater solution) before being stored for later analysis at the Natural History Museum, London. In 2006, the Steedman's preserving fluid was replaced by 80% alcohol and the planktonic ostracods were picked out and sorted to species. Specimens of

Table 1. Density of *Euconchoecia*.

Station 54001 24°12′ N 58°40′ E	Depth (metres)	Day/ Night	Ostracod nos. Totals	Ostracod nos. Per 1000 cubic metres	*Euconchoecia* Totals	*Euconchoecia* Per 1000 cubic metres	*Euconchoecia* Percentage
#21	0 – 50	Night	14, 456	5616	6412	2491	44.4%
#27	0 – 50	Day	2796	2186	2238	1750	80.0%
#20	50 – 100	Night	23, 336	10, 115	6540	2835	28.0%
#26	50 – 100	Day	9884	8433	6288	5365	63.6%
#25	100 – 150	Day	19, 816	15, 530	152	119	0.8%
#19	100 – 157	Night	19, 688	7646	41	16	0.2%
#03	150 – 200	Day	12, 684	4899	34	13	0.3%
#06	152 – 201	Night	6834	2489	8	3	0.1%

Euconchoecia were exceptionally abundant (Table 1) in the wind-mixed layer (the upper 100 m) overlying the strong oxycline leading to a depth zone with almost no measurable oxygen that extended from 90 to 1200 m.

Angel's 1973 Atlantic samples were re-examined: 32 females and nine males of *E. chierchiae* were measured. One adult of each sex was selected from the sorted material, placed on a cavity slide and stained with lignin pink dissolved in lactophenol for 15 min. The stained specimens were dissected using a stereoscopic microscope and mounted on microscope slides as temporary preparations in lactophenol.

The vial of the type material of *E. aculeata* contained four adults, two females and two males. The female in the best condition was selected as the lectotype and the male in the best condition was the paralectotype. Both specimens were clogged with detrital particles, which had accumulated over the century since they had been collected; at least some of this detritus probably resulted from when the specimens were first transferred into alcohol, if the salt water had not been fully washed out. This detrital material was successfully removed from these fragile specimens by briefly placing them in an ultrasonic bath. The specimens were measured, dissected and mounted in lactophenol, but without staining because such old specimens do not take up stain.

Initial examination of adults from the Gulf of Oman showed two size groups of both males and females. It was suspected that there were two species, so large numbers of adult males and females of each size category were measured. The large females measured 1.42 ± 0.06 mm (n = 100), the small females measured 1.04 ± 0.05 mm (n = 48), the large males measured 1.15 ± 0.04 mm (n = 100) and the small males measured 1.00 ± 0.03 mm (n = 36). Selected individuals were stained in lignin pink dissolved in lactophenol for 15 min, then dissected in lactophenol on a cavity slide using a stereoscopic microscope. These slides were examined under an Olympus BH2 compound microscope using Nomarski illumination (differential interference contrast). A standard set of measurements was made of the carapaces, limbs and setae (see Angel and Blachowiak-Samolyk 2006). These measurements were standardized by expressing them as percentages of the individual carapace lengths. A camera lucida on the Olympus BH2 with differential interference contrast was used to make pencil drawings of both the complete animal and the individual dissected parts. These sketches were scanned and re-drawn using ADOBE ILLUSTRATOR and collated in ADOBE PHOTOSHOP.

The nomenclature of Skogsberg (1920) for the structure and setae of the antennae, mandible, maxilla, fifth to seventh limbs, and caudal furca has been used throughout. By convention, males would be described first, but as the *E. aculeata* male dissection was incomplete, the female is described first and to be consistent the females are described first for all species. On the first antenna of each specimen the detachment point varied between individuals, so accurate measurements of the first segment were not comparative, for this reason only measurements for the other segments have been recorded.

Systematics

Class **OSTRACODA** Latreille, 1802
Subclass **MYODOCOPA** Sars, 1866
Order **HALOCYPRIDA** Dana, 1853
Suborder **HALOCYPRIDINA** Dana, 1853
Family **HALOCYPRIDIDAE** Dana, 1853
Subfamily **EUCONCHOECINAE** Poulsen, 1969
Genus ***Euconchoecia*** Müller, 1890

Diagnosis

Carapace usually smooth, lacking any sculpture, shape elongate, rostra well-developed but asymmetrical; posterior dorsal corners usually pointed. The "asymmetrical glands" open almost symmetrically just below posterior dorsal corner. Frontal organ long, extends beyond second segment of first antennae (Skogsberg 1920), but ± length of first antenna. First antennae (A1) show marked sexual dimorphism, in both sexes fourth segment bears ventrally more than 20 bundle setae of similar length and thickness. Terminal A1 segment bears four or five unarmed setae. In males, two setae are long and powerful; the longest seta more than three times the length of bundle sensory setae and 50% carapace length (CL). Protopodite of second antenna (A2) large and powerful. In males A2 is 35–40% CL. A2 endopodite lacks any c-, d- and e-setae (that are typical of other halocyprids), f- and g-setae very long. The male right A2 endopodite with elongate hooked clasping organ, with long proximal shank with h-, i- and j-setae inserted distally, end piece long, curved. Left A2 endopodite has "hook" reduced to just straight basal shank, also carries three setae terminally. Female A2 endopodite without c-, d- and e-setae, f- and g-setae shorter than in male. First segment with small verucca carrying a single seta (similar in length to i-seta of male). Coxale of mandibular protopodite elongate triangular structure contains complex musculature that generates the biting action. Distal end of the coxale has three parallel rows of teeth: pars incisiva, distal tooth list, and narrower proximal tooth list. Basale with distal edge of sub-serrate teeth, one tubular tooth and one dagger-shaped tooth; laterally with four long setae and a plumose seta. The exopodite consists of a long plumose seta. The segmented endopodite with a short, bare dorsal seta sits on first segment plus three spinose ventral setae. Second segment with one spinose ventral seta and two dorsal spinose setae. Terminal segment with seven spinose setae; the longest almost as long as carapace. Basal segment of maxilla with five anterior, one lateral and four posterior setae. Distal segment short and wide with six claw setae, the posteriormost is longer than others, anterior seta with secondary spines, ornamented with short fine hairs. Ventral edge of basale of fifth limb with five spinose pointed setae, and laterally two plumose setae. First endopodite segment with two ventral setae and one dorsal seta; all spinose. Second segment with three curved unequal terminal claw setae; central claw is longest. Main axes of both fifth and sixth limbs in both sexes are endopodites, the dorsal seta on the basale is a remnant exopodite (see Boxshall 1998; Kornicker 2003). In females, basale of sixth limb with ventrally three spinose setae plus one plumose seta, laterally a plumose seta, dorsally a single seta. First endopodite segment with two ventral setae. Second segment with single spinose setae ventrally and dorsally. Terminal segment with three unequal serrate setae. Male sixth limb differs from female's. Ventral surface of the basale with five spinose setae, terminal setae very long, subequal, smoothly curved with long hairs. Seventh limb in both sexes with two setae one long, one short. Caudal furca with seven pairs of claw setae that diminish in size dorsally, all with secondary spines along trailing edge, plus dorsally small unpaired seta with secondary spines. Between the first and second pairs of claw setae a verruciform process. Intromittent organ broad, widens distally with rounded tip.

Remarks

This genus is exceptional among halocyprid ostracods in that the females retain their eggs in a brood pouch within the carapace, releasing them as they complete the first juvenile instar. The earliest juvenile instar has two pairs of caudal furca spines and at each moult an extra pair is added. Most adult halocyprids have eight pairs of caudal furca spines, whereas *Euconchoecia* has seven pairs, which poses the question of whether *Euconchoecia* moult just five times from hatching to maturation rather than the usual six of *Conchoecia* Dana, 1853. If *Euconchoecia* has evolved neotenously from the *Conchoecia* type of life cycle by a reduction in the number of moults from six to five, such an abbreviated life cycle would enable populations to respond quicker to any changes resulting from upwelling events.

Euconchoecia chierchiae Müller, 1890
(Figures 1–6, 21A,B)

Euconchoecia chierchiae Müller, 1890: 277, Pl. XXVIII, fig. 1–10. Brady, 1902: 190, Pl. XXIV, fig. 9–15. Vavra, 1906: 29, Pl. 1, fig. 1–6. Skogsberg, 1920: 740, fig. CXLVIII–CLI. Deevey, 1968: 116, fig. 62. Poulsen, 1969: 38, fig. 12, 13. Tseng, 1969: 2, fig. 1. George, 1977: fig. 1, 2.

Paraconchoecia oblonga Cleve, 1900: 40.

Material

The material is not "type" material, but material collected from Discovery station 8281 (see above). Permanent preparations of dissected specimens used to prepare the illustrations in this paper have been deposited at the Natural History Museum, London: registration number BMNH 2009.316 for the female and BMNH 2009.317 for the male. Registration numbers BMNH 2009.318–327 are for the 32 females and 9 males retained in 80% ethyl alcohol.

Description

A full redescription is merited because this is the type species for the genus. The meristic characters of the carapaces of both sexes, the frontal organs, first and second antennae, mouthparts and limbs are listed in Tables 2–9, together with comparative data for the other species examined: *E. aculeata* Scott 1894, and the two new species from the Gulf of Oman.

Female

Carapace (Figure 1A, B). Mean length 1.24 ± 0.05 mm ($n = 32$). Carapace of exemplar specimen (Table 2) with length 1.28 mm, height 0.56 mm and breadth 0.50 mm. Height : length ratio 43.8%, breadth : length ratio 39.1%. Carapace unsculptured. In lateral view slightly elongate: maximum height just posterior to mid-length. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a small spine. Spine slightly smaller on left valve. Dorsal margin arcs anteriorly up towards dorsal end of hinge between carapace valves. Both rostra curve ventrally, the left rostrum is the longer and more pointed. The "asymmetrical" glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal organ (Table 2; Figure 1C). Frontal organ fused into a single slender structure with rounded end that is just shorter than A1 and 18.9% CL.

First antenna (Table 3 Figure 1C). With five segments, but suture between fourth and fifth segments ill-defined. Limb length ~ 31% CL. Fourth segment with ~ 24 thin walled bundle setae all 17% CL. Fifth segment with four more unequal setae; a-seta quite short 5.1% CL; b-seta 9.4% CL; c-seta 17.2% CL; d-seta 13.9% CL.

Second antenna (Table 3; Figure 1D). Protopodite 27.7% CL. Length of first exopodite segment ~ half protopodite. Most swimming setae similar in length to protopodite, all but the shortest terminal seta have long hairs distally. Endopodite (Figure 1E) with short, pointed, bare a- and b-setae. There are no c-, d- or e-setae. The f- and g-setae, respectively, 26.6% CL and 44.9% CL. The i-seta 13.3% CL, but h- and j-setae are absent.

Mandible (Table 4; Figure 2A,B). Coxale toothed edge of pars incisiva has two large and 10 small smooth teeth. Distal tooth list slightly narrower with two large tusk-like teeth and 10 small smooth teeth. The proximal tooth list very narrow, with two large and five small teeth. Outer margin of toothed edge of basal endite with a large dagger-shaped tooth, a slightly smaller, rounded, tubular tooth and six subserrate teeth. Two spinose setae are inserted laterally on basal endite. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with one short, bare, subterminal, dorsal seta and three finely spinose ventral setae. Second segment with one ventral and two dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

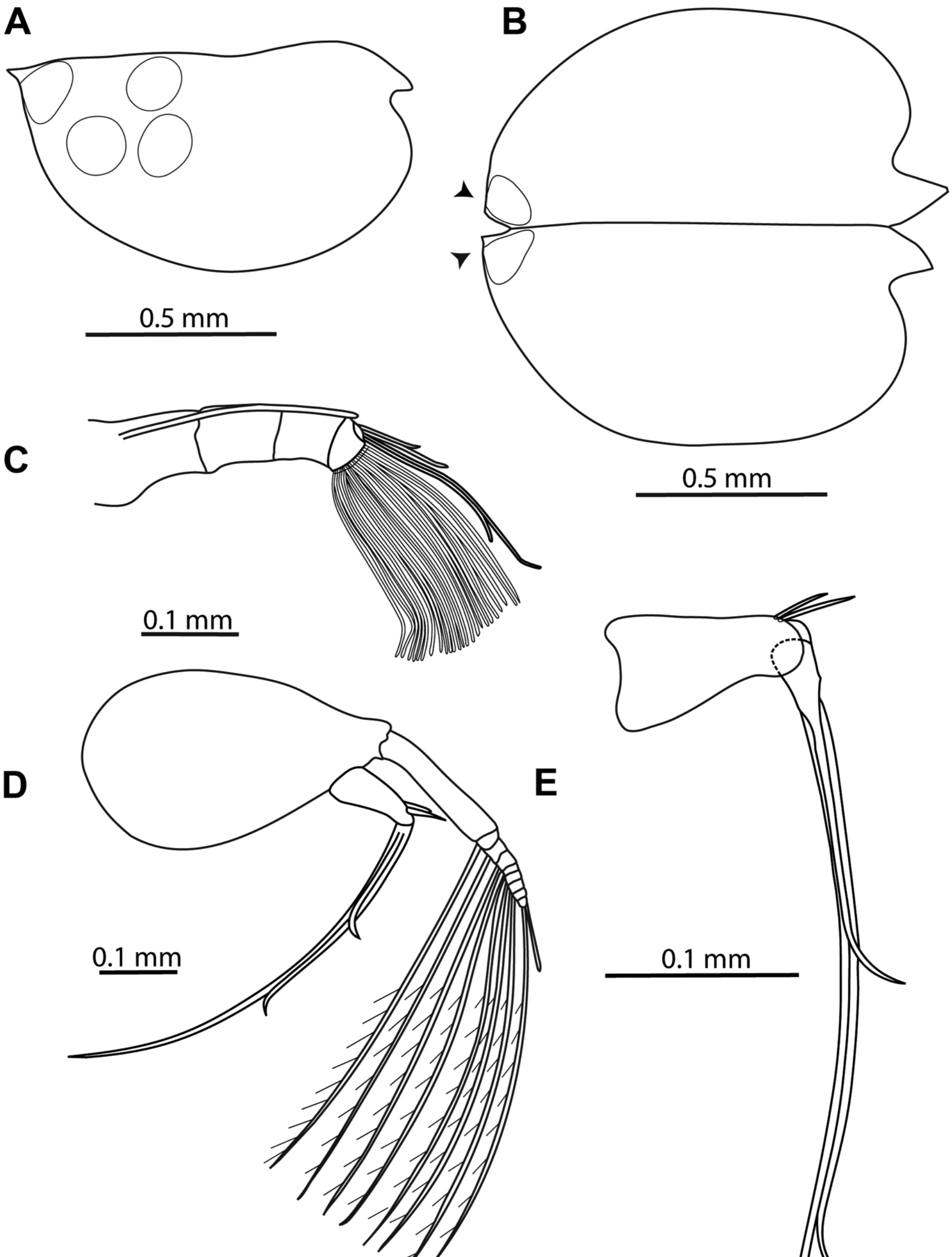


Figure 1. *Euconchoecia chierchiae* female: (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside, (E) endopodite viewed from inside.

Table 2. Female *Euconchoecia* species differences.

Female	*E. chierchiae*	*E. aculeata*	*E. omanensis*	*E. hormuzensis*
Carapace				
length	1.28 mm	1.28 mm	1.42 mm	1.00 mm
height	0.56 mm	0.64 mm	0.46 mm	0.42 mm
breadth	0.50 mm	0.42 mm	0.40 mm	0.40 mm
height : length %	43.8%	50.0%	32.4%	42.0%
breadth : length %	39.1%	32.8%	28.2%	40.0%
PDC, left tip to posterior hinge (% CL)	6.3%	6.6%	13.0%	11.0%
PDC, right tip to posterior hinge (% CL)	7.0%	9.8%	15.8%	11.5%
Rostrum, left tip to anterior hinge (% CL)	14.5%	15.6%	15.1%	12.0%
Rostrum, right tip to anterior hinge (% CL)	13.3%	12.1%	11.6%	12.0%
Incisure, left rostrum tip to inner edge (% CL)	12.5%	14.5%	14.1%	10.0%
Incisure, right rostrum tip to inner edge (% CL)	9.4%	10.5%	11.3%	9.5%
Frontal organ				
stem and capitulum length (% CL)	18.9%	22.3%	18.7%	20.3%
length relative to antenna 1	slightly shorter	marginally longer	significantly longer	slightly longer

Notes: $n = 1$ for each species
% CL, % of carapace length; PDC, posterior dorsal corner.

Maxilla (Table 4; Figure 2C). Basal segment with five anterior, one lateral and four posterior setae. Distal segment comparatively short and wide with six terminal claw setae, the posteriormost is longest, anterior claw with secondary spines.

Fifth limb (Table 5; Figure 2D). Ventrally basale with five (2+1+2) setae all with secondary spines; laterally two plumose setae, dorsally a single long spinose seta – the remnant of the exopodite. First segment with two ventral setae and one dorsal seta, all spinose. Second segment with three unequal, curved terminal claw setae; middle claw the longest 5.7% CL.

Sixth limb (Table 5; Figure 2E). Basale with one proximal, two medial ventral spinose setae and a distal plumose seta, laterally a plumose seta and dorsally a terminal spinose seta. First endopodite segment with two ventral setae. Second segment with a single spinose seta both ventrally and dorsally. Third segment with three unequal spinose, terminal claw setae; longest middle claw 10.4% CL.

Caudal furca (Table 5; Figure 2F). Seven pairs of claw setae diminish in size dorsally; longest claw 15.2% CL. All have secondary spines along their trailing edges. Dorsal to

Table 3. Female *Euconchoecia* species differences.

Female	*E. chierchiae*	*E. aculeata*	*E. omanensis*	*E. hormuzensis*
Antenna 1				
length segment 2 (% CL)	7.4%	8.2%	6.5%	7.0%
length segment 3 (% CL)	4.3%	7.2%	4.4%	3.0%
length segment 4 (% CL)	1.6%	4.5%	3.3%	2.4%
approximate total length	31.0%	34.0%	35.0%	37.0%
bundle setae number	24	24	24	24
bundle setae length (% CL)	17.0%	17.0%	9.2%	16.3%
a-seta (% CL)	5.1%	3.1%	2.1%	3.8%
b-seta (% CL)	9.4%	6.1%	3.5%	5.5%
c-seta (% CL)	17.2%	14.5%	10.0%	17.0%
d-seta (% CL)	13.9%	11.5%	7.7%	13.5%
Antenna 2				
protopodite (% CL)	27.7%	29.3%	24.6%	30.0%
exopodite 1 (% CL)	14.8%	13.7%	10.2%	13.0%
exopodite 2–9 (% exopodite 1)	53.9%	45.7%	37.9%	53.8%
longest swimming seta (% CL)	27.0%	30.9%	24.1%	24.5%
shortest swimming seta (% CL)	3.8%	3.1%	2.1%	2.0%
endopodite segment 1 (% CL)	9.2%	9.4%	7.2%	9.3%
a-seta (% CL)	1.8%	1.2%	1.6%	2.3%
b-seta (% CL)	3.1%	3.5%	3.2%	3.5%
endopodite segment 2 (% CL)	4.1%	2.3%	2.3%	2.0%
f-seta (% CL)	26.6%	25.4%	17.8%	24.0%
g-seta (% CL)	44.9%	35.2%	23.2%	43.5%
i-seta (% CL)	13.3%	23.0%	7.2%	11.5%

Notes: $n = 1$ for each species
% CL, % of carapace length.

the paired spines is a single seta with bilateral secondary spines. Between the first and second pairs of claw setae is a verruciform process.

Male

Carapace (Figure 3A,B). Mean length 1.24 ± 0.06 mm ($n = 9$). Carapace of exemplar specimen (Table 6) with length 1.26 mm, height 0.70 mm and breadth 0.60 mm. Height : length ratio 55.6%, breadth : length ratio 47.6%. Carapace unsculptured. Maximum height just anterior to mid-length. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a small spine. On the left valve the spine is slightly smaller. Dorsal margin arcs anteriorly up towards dorsal end of hinge between carapace valves. Both rostra forward pointing and of the same length. The "asymmetrical" glands open at a similar height on the posterior margin of each valve just below the spine at the posterior dorsal corner.

Frontal organ (Table 6; Figure 3C). Frontal organ is fused into a slender structure with a rounded end, shorter than A1 and 23.2% CL.

Table 4. Female *Euconchoecia* species similarities.

Female	*E. chierchiae*	*E. aculeata*	*E. omanensis*	*E. hormuzensis*
Mandible				
basale	1 plumose	1 plumose	1 plumose	1 plumose
endopodite segment 1 dorsal setae	1	1	1	1
endopodite segment 1 ventral setae	3	3	3	2
endopodite segment 2 dorsal setae	2	2	2	2
endopodite segment 2 ventral setae	1	1	1	1
endopodite segment 3 terminal setae	7	7	7	7
endopodite segment 3 longest claw (% CL)	15.8%	16.0%	12.9%	16.0%
endopodite segment 3 longest claw (% limb)	93.2%	93.2%	83.9%	94.1%
teeth on basal endite	2 + 6	2 + 6	2 + 6	2 + 6
pars incisiva	2 + 10	2 + 10	2 + 10	2 + 10
distal tooth list	2 + 10	2 + 10	2 + 10	2 + 10
proximal list	2 + 5	2 + 5	2 + 5	2 + 5
setae laterally on endite	2 +2	2 + 2	2 + 2	2 + 2
exopodite	1 plumose	1 plumose	1 plumose	1 plumose
Maxilla				
basal segment anterior setae	5	5	5	5
basal segment lateral setae	1	1	1	1
basal segment posterior setae	4	4	4	4
terminal spines	fine hairs	fine hairs	fine hairs	fine hairs
distal segment claw setae	3	3	3	3
distal segment normal setae	3	3	3	3

Notes: $n = 1$ for each species.
% CL, % of carapace length.

First antenna (Table 7; Figure 3C). With five well-defined segments. Limb length ~ 31% CL. As in the female, fourth segment with ~ 24 thin walled bundle setae all 17.5% CL. Fifth segment with five more unequal setae: a-seta 8.3% CL; b-seta 18.1% CL; c-seta 38.9% CL; d-seta 42.5% CL; e-seta 65.1% CL.

Second antenna (Table 7; Figure 3D). Protopodite 38.5% CL. Length of first segment of exopodite ~ half protopodite. Most swimming setae similar in length to protopodite, all but the shortest have long hairs distally. Endopodite with short, pointed a- and b-setae. There are no c-, d- or e-setae. The f- and g-setae respectively 22.4% CL and 79.8% CL. Right endopodite (Figure 4B) with elongated clasping organ in form of hook with long proximal shank and very long curved end piece 9.1% CL. The h-, i- and j-setae attached distally to basal shank, h-seta is short 3.4% CL and curves over bases of other two, i-seta longest 15.9% CL. Left endopodite (Figure 4A) "hook" reduced to just basal shank with three setae.

Mandible, maxilla, fifth limb (Tables 8, 9; Figures 4C–E, 5A). Structure and arrangement of setae for mandible, maxilla and fifth limb are same as for female.

Sixth limb (Table 9; Figure 5B). Basale with five spinose setae ventrally, one lateral spinose seta and one bare dorsal exopodal seta. First endopodite segment with two

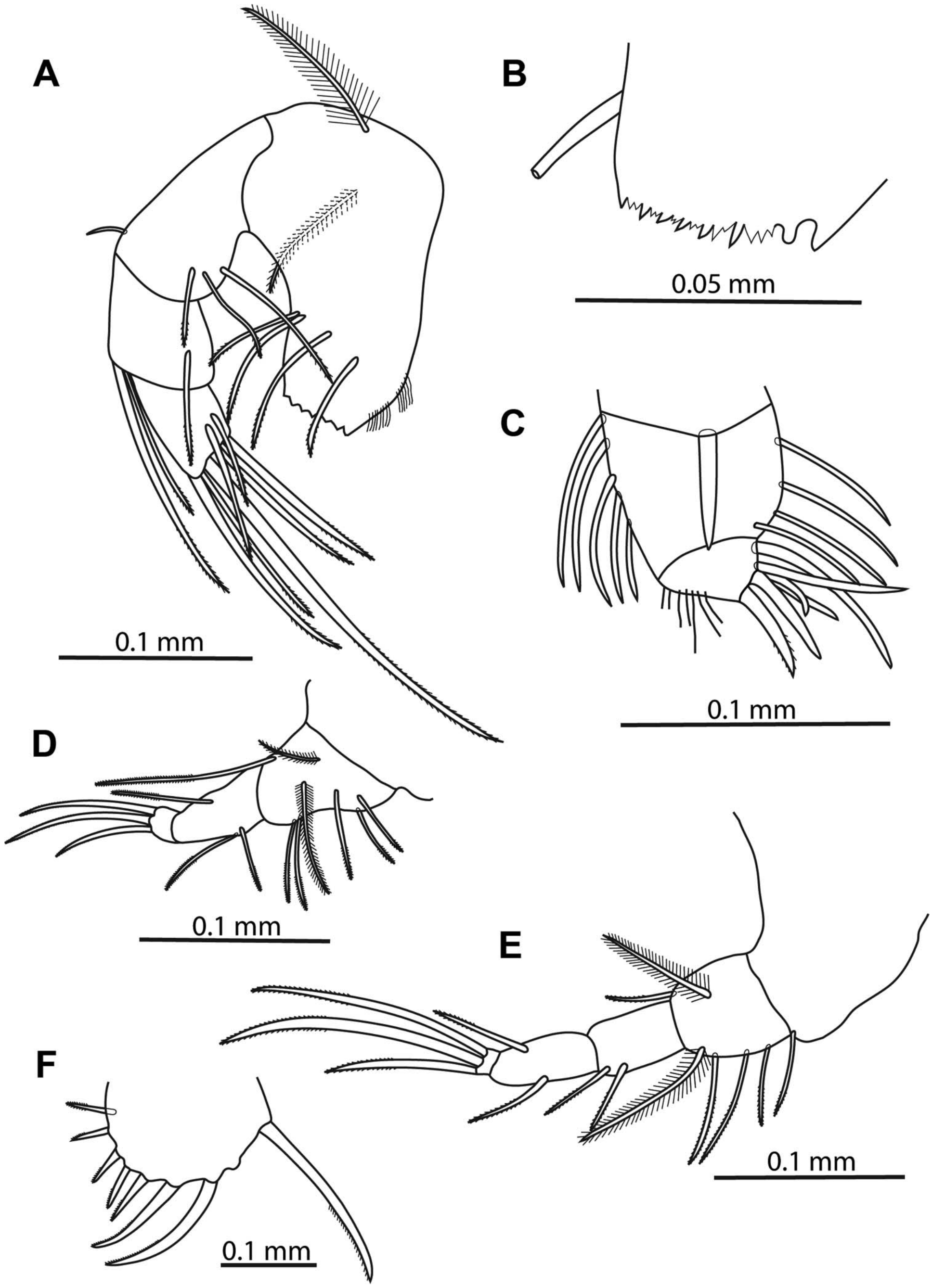


Figure 2. *Euconchoecia chierchiae* female: (A) mandible, coxale not shown, (B) basal endite of mandible, (C) maxilla, (D) fifth limb, (E) sixth limb, (F) caudal furca.

Table 5. Female *Euconchoecia* species similarities.

Female	*E. chierchiae*	*E. aculeata*	*E. omanensis*	*E. hormuzensis*
Fifth limb				
basale ventral setae	2 + 2 + 1	2 + 2 + 1	2 + 2 + 1	2 + 2 + 1
basale lateral setae	2	2	2	2 plumose
basale dorsal setae	1 long	1 long	1 long	1 long
endopodite segment 1 ventral setae	2	2	2	2
endopodite segment 1 dorsal setae	1	1	1	1
height/length %	45.2%	56.3%	76.0%	57.7%
longest terminal seta % CL	5.7%	6.0%	4.1%	*5.5%*
longest seta/length segment 2	341.2%	554.5%	522.2%	525.0%
longest seta/ length limb	55.8%	58.7%	58.0%	60.9%
Sixth limb				
basale ventral setae	3 + 1 plumose	3 + 1 plumose	3 + 1 plumose	3 + 1 plumose
basale lateral setae	1 plumose	1 plumose	1 plumose	1 plumose
basale dorsal setae	1	1	1	1
endopodite segment 1 ventral setae	2	2	2	2
endopodite segment 1 dorsal setae	0	0	0	0
endopodite segment 2 ventral setae	1	1	1	1
endopodite segment 2 dorsal setae	1	1	1	1
segment 2 height /length %	47.4%	55.6%	44.1%	35.0%
longest seta % CL	10.4%	8.1%	7.1%	8.5%
longest seta % segment 2	278.9%	461.1%	238.2%	170.0%
longest seta % limb	77.9%	159.6%	52.9%	50.0%
Caudal furca				
paired claws	7 pairs	7 pairs	7 pairs	7 pairs
longest claw % CL	15.2%	14.1%	10.4%	12.0%
unpaired dorsal seta	1 seta	1 seta	1 seta	1 seta

Notes: $n = 1$ for each species.
% CL, % of carapace length.

ventral setae. Second endopodite segment with a single seta both ventrally and dorsally. Third segment with three subequal terminal setae, very long, evenly curved ventrally with long hairs 28.6% CL.

Caudal furca (Table 9; Figure 5C). Structure and arrangement of furcal claws similar to female. The longest claw is 18.7% CL.

Intromittent organ (Table 9; Figure 5C). Male copulatory appendage is exceptionally long, 27.4% CL.

Remarks

The original description of *E. chierchiae* by Müller (1890) and subsequent redescription (Müller 1906) specified a wide size range; females from 1.15 to 1.53 mm and males from 1.15 to 1.45 mm. Size is a significant taxonomic feature of halocyprid ostracods, so a wide range such as this often suggests that there may be more than one species present. The redescriptions of *E. chierchiae* by Brady (1902) and by Vavra (1906) were considered doubtful by Skogsberg (1920), and the illustration by Skogsberg (1920) of a female specimen in lateral aspect differs from those of Müller (1890, 1906). *Euconchoecia chierchiae* as described by George (1977) from the Indian Ocean appears very similar to Atlantic *E. chierchiae* as described by Müller (1890). Deevey (1968) and later Angel (1999) identified and illustrated *E. chierchiae* from

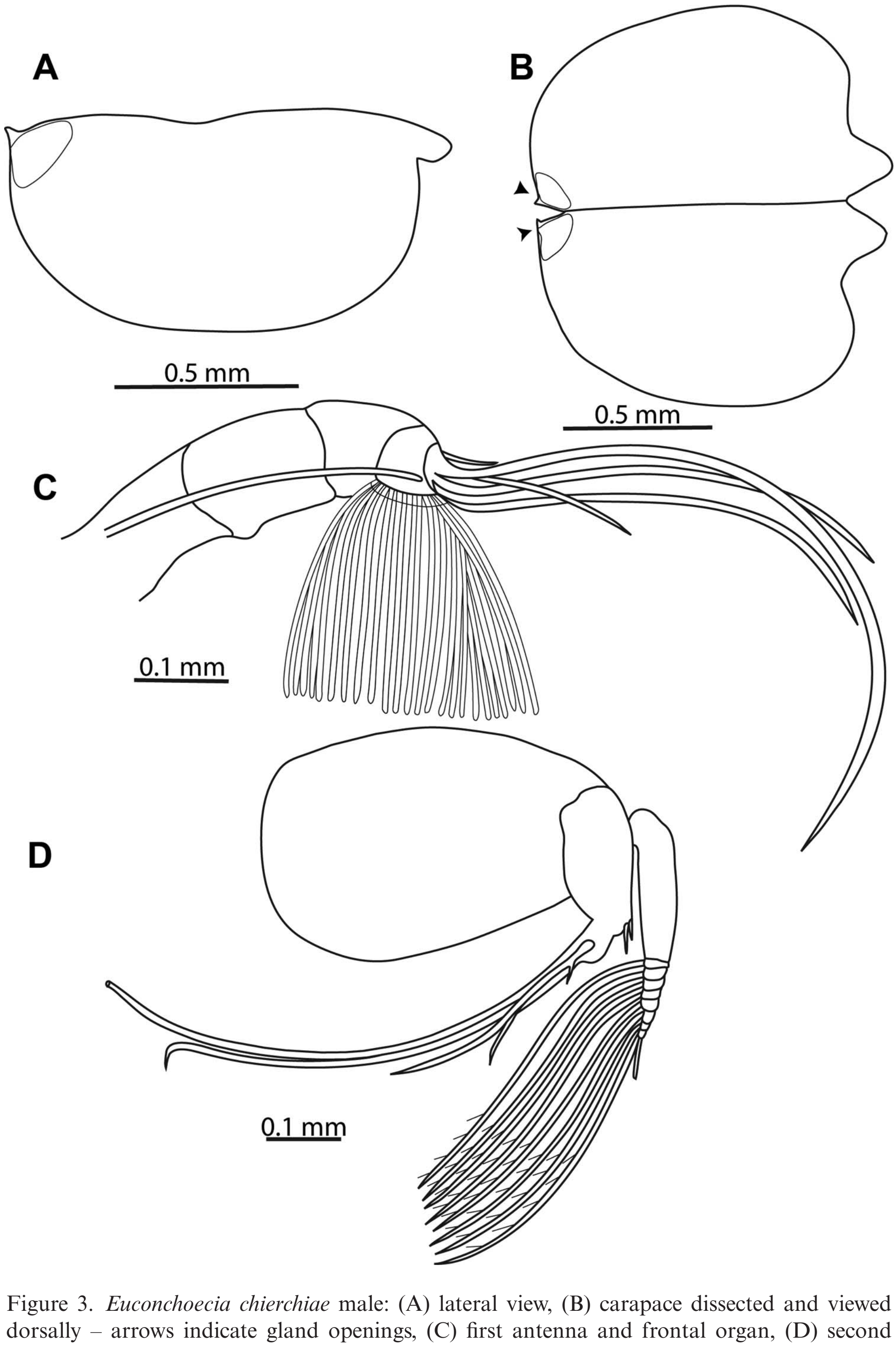


Figure 3. *Euconchoecia chierchiae* male: (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside.

Table 6. Male *Euconchoecia* species differences.

Male	*E. chierchiae*	*E. aculeata*	*E. omanensis*	*E. hormuzensis*
Carapace				
length	1.26 mm	1.06 mm	1.20 mm	0.98 mm
height	0.70 mm	0.60 mm	0.44 mm	0.40 mm
breadth	0.60 mm	0.46 mm	0.40 mm	0.40 mm
height/length %	55.6%	56.6%	36.7%	40.8%
breadth/length %	47.6%	43.4%	33.3%	40.8%
PDC, left tip to posterior hinge (%CL)	7.5%	0.9%	9.6%	8.7%
PDC, right tip to posterior hinge (%CL)	9.5%	1.9%	12.9%	9.7%
Rostrum, left tip to anterior hinge (%CL)	14.3%	21.7%	13.3%	11.7%
Rostrum, right tip to anterior hinge (%CL)	14.3%	28.8%	12.9%	9.7%
Incisure, left rostrum tip to inner edge (%CL)	15.1%	14.6%	15.0%	12.8%
Incisure, right rostrum tip to inner edge (%CL)	12.7%	13.7%	14.6%	11.2%
Frontal organ				
stem and capitulum length (% CL)	23.2%	22.2%	31.3%	21.1%
length relative to antenna 1	shorter	slightly shorter	significantly longer	slightly longer

Notes: $n = 1$ for each species.
% CL, % of carapace length; PDC, posterior dorsal corner.

off Bermuda, and recently specimens from waters west of Bermuda have had the cytochrome oxidase type 1 gene (*COI*) sequenced (Angel, personal communication). However, critical comparisons of these two authors' descriptions and figures deviate from those of both Müller (1906) and Skogsberg (1920), and the attributions of their specimens to this species remain open to question (Figure 6). There is a now a need for systematic and molecular studies to clarify the status of this species. Unfortunately, despite the remarkably high abundances of *Euconchoecia* in tropical waters especially in the Pacific, no sequencing of this genus has been undertaken**,** and the Gulf of Oman material is unsuitable for molecular sequencing because it was initially preserved in formalin.

Euconchoecia aculeata (Scott, 1894)
(Figures 7–10, 21C, D)

Halocypris aculeata Scott, 1894: S 142, Pl. XV, figs. 5, 6, 33, 38.

Euconchoecia aculeata Cleve, 1905: 131. Müller, 1906: 129, Pl. XXXII, figs. 18–20, 22–26. Müller, 1912: 95. Poulsen, 1969: 41, fig. 15. Tseng, 1969: 18, fig 4. George, 1977: fig. 1–5.

Table 7. Male *Euconchoecia* species differences.

Male	*E. chierchiae*	*E. aculeata*	*E. omanensis*	*E. hormuzensis*
Antenna 1				
length segment 2 (% CL)	9.1%	7.1%	10.4%	9.7%
length segment 3 (% CL)	4.8%	8.6%	10.2%	6.4%
length segment 4 (% CL)	3.8%	6.1%	4.6%	3.7%
length segment 5 (% CL)	2.8%	2.8%	3.8%	1.6%
approximate total length	31.0%	32.7%	35.0%	34.0%
bundle setae number	approximately 24	approximately 24	approximately 24	approximately 24
bundle setae length (% CL)	17.5%	n.d.	14.4%	17.1%
a-seta (% CL)	8.3%	n,d.	8.8%	3.7%
b-seta (% CL)	18.1%	n.d.	15.0%	4.6%
c-seta (% CL)	38.9%	n.d.	18.3%	13.8%
d-seta (% CL)	42.5%	n.d.	32.1%	34.2%
e-seta (% CL)	65.1%	n.d.	46.3%	50.0%
Antenna 2				
protopodite (% CL)	38.5%	38.2%	37.1%	40.8%
exopodite 1 (% CL)	17.1%	15.6%	14.0%	15.3%
exopodite 2–9 (% exopodite 1)	51.2%	59.1%	58.2%	58.3%
longest swimming seta (% CL)	38.9%	31.6%	34.6%	27.0%
shortest swimming seta (% CL)	3.3%	3.1%	2.5%	1.6%
endopodite segment 1 (% CL)	15.1%	10.7%	14.8%	14.8%
a-seta	1.8%	1.8%	1.6%	1.9%
b-seta	3.8%	1.5%	3.2%	3.7%
endopodite segment 2 (% CL)	5.8%	4.8%	3.8%	5.6%
f-seta (% CL)	22.4%	36.8%	39.2%	39.8%
g-seta (% CL)	79.8%	38.4%	60.0%	119.9%
right clasper shank length	9.1%	1.7%	5.4%	6.4%
h-seta (% CL)	3.4%	1.9%	2.9%	2.8%
i-seta (% CL)	15.9%	16.0%	19.2%	20.7%
j-seta (% CL)	6.3%	9.2%	9.6%	9.7%

Notes: $n = 1$ for each species.
% CL, carapace length; n.d., no data.

Type material

Permanent preparations of the dissected specimens selected as lectotype and paralectotype and used in this detailed description of the species are deposited at the Natural History Museum, London registration number BMNH 2009.328 for the lectotype (female) and BMNH 2009.329 for the paralectotype (male). The remaining undissected paralectotypes retain the original registration numbers, 1893.4.22.14–17.

Description

The meristic characters of the carapaces of males and females, and the frontal organs, first and second antennae, mouthparts and limbs are listed in Tables 2 to 9 together with comparative data for the other species described here.

Female

Carapace (Figure 7A,B). Material deposited in the Natural History Museum contained two females: one measured 1.18 mm. The other, selected as lectotype (Table 2),

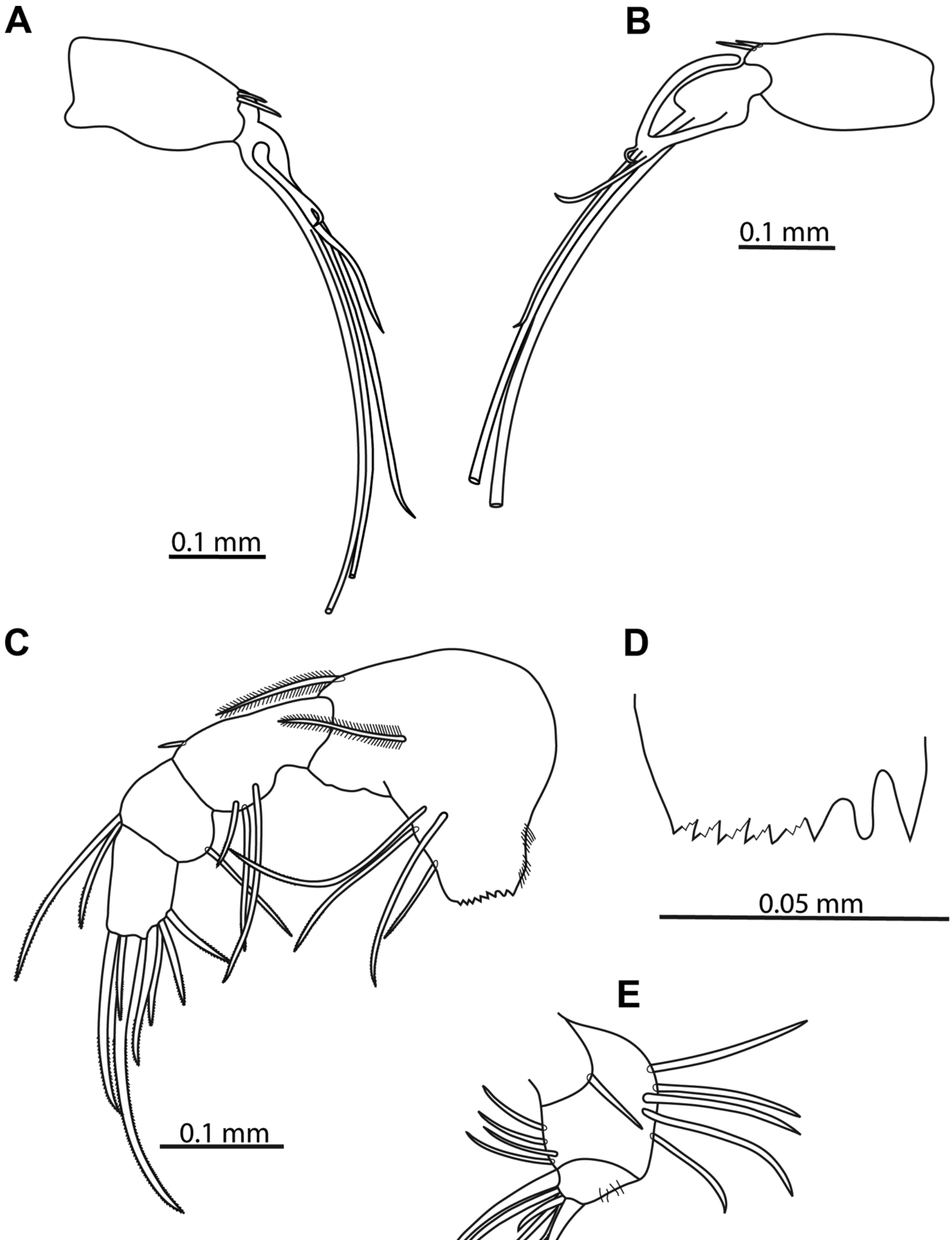


Figure 4. *Euconchoecia chierchiae* male: (A) left endopodite viewed from inside, (B) right endopodite viewed from inside, (C) mandible, coxale not shown, (D) basal endite of mandible, (E) maxilla.

Table 8. Male *Euconchoecia* species similarities.

Male	*E. chierchiae*	*E. aculeata*	*E. omanensis*	*E. hormuzensis*
Mandible				
basale	1 plumose	n.d.	1 plumose	1 plumose
endopodite segment 1 dorsal setae	1	1	1	1
endopodite segment 1 ventral setae	3	3	3	3
endopodite segment 2 dorsal setae	2	2	2	2
endopodite segment 2 ventral setae	1	1	1	1
endopodite segment 3 terminal setae	7	7	7	7
endopodite segment 3 longest claw (%.CL)	16.5%	18.2%	16.9%	18.9%
endopodite segment 3 longest claw (% limb)	79.0%	87.5%	96.40%	96.1%
teeth on basal endite	2 + 6	n.d.	2 + 6	2 + 6
pars incisiva	2 + 10	n.d.	2 + 10	2 + 10
distal tooth list	2 + 10	n.d.	2 + 10	2 + 10
proximal list	2 + 5	n.d.	2 + 5	2 + 5
setae laterally on endite	2 + 2	n.d.	2 + 2	2 + 2
exopodite	1 plumose	n.d.	1 plumose	1 plumose
Maxilla				
basal segment anterior setae	5	5	5	5
basal segment lateral setae	1	1	1	1
basal segment posterior setae	4	4	4	4
terminal spines	fine hairs	fine hairs	fine hairs	fine hairs
distal segment claw setae	3	3	3	3
distal segment normal setae	3	3	3	3

Notes: $n = 1$ for each species.
% CL, carapace length; n.d., no data.

has length 1.28 mm, height 0.64 mm and breadth 0.42 mm. Height : length ratio was 50.0%, breadth : length ratio was 32.8%. Carapace unsculptured. Lateral view elongate. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a small spine. Spine smaller on left valve. Dorsal margin straight and parallel to the ventral margin. Both rostra curve ventrally, with the left rostral process longer and more pointed. The "asymmetrical" glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal organ (Table 2; Figure 7C). Frontal organ fused into a slender structure with a rounded end that is slightly longer than A1 and 22.3% CL.

First antenna (Table 3; Figure 7C). With five segments, but suture between fourth and fifth segments ill-defined. Limb length ~ 34% CL. Fourth segment with ~ 24 thin

Table 9. Male *Euconchoecia* species similarities.

Male	*E. chierchiae*	*E. aculeata*	*E. omanensis*	*E. hormuzensis*
Fifth limb				
basale ventral setae	2 + 2 + 1	n.d.	2 + 2 + 1	2 + 2 + 1
basale lateral setae	2	n.d.	2	2
basale dorsal setae	1 long	n.d.	1 long	1 long
endopodite segment 1 ventral setae	2	n.d.	2	2
endopodite segment 1 dorsal setae	1	n.d.	1	1
height/length %	44.8%	n.d.	53.1%	46.4%
longest terminal seta % CL	4.4%	n.d.	5.6%	6.0%
longest seta/length segment 2	420.0%	n.d.	450.0%	375.0%
longest seta/ length limb	30.1%	n.d.	61.4%	71.4%
Sixth limb				
basale ventral setae	5	5	5	5
basale lateral setae	1	1	1	1
basale dorsal setae	1	1	1	1
endopodite segment 1 ventral setae	2	2	2	2
endopodite segment 1 dorsal setae	0	0	0	0
endopodite segment 2 ventral setae	1	1	1	1
endopodite segment 2 dorsal setae	1	1	1	1
segment 2 height /length %	30.4%	47.5%	35.0%	38.2%
longest seta % CL	28.6%	n.d.	30.4%	34.7%
longest seta % segment 2	313.0%	n.d.	365.0%	400.0%
longest seta % limb	150.0%	n.d.	135.2%	141.7%
Caudal furca				
paired claws	7 pairs	7 pairs	7 pairs	7 pairs
longest claw % CL	18.7%	17.5%	12.5%	14.5%
unpaired dorsal seta	1	1	1	1
Intromittent organ				
length % CL	27.4%	27.4%	19.6%	20.9%

Notes: $n = 1$ for each species.
% CL, carapace length; n.d., no data.

walled bundle setae all 17.0% CL. Fifth segment with four more unequal setae, the a-seta short 3.1% CL; b-seta 6.1% CL; c-seta 14.5% CL; d-seta 11.5% CL.

Second antenna (Table 3; Figure 7D). Protopodite 29.3% CL. Length of first exopodite segment approximately half protopodite. Most swimming setae are similar length to protopodite, all but the shortest terminal seta have long hairs distally. Endopodite (Figure 7E) with short, pointed, bare a- and b-setae. There are no c-, d- or e-setae. The f- and g-setae respectively 25.4% CL and 35.2% CL. The i-seta 23.0% CL, but the h- and j-setae are absent.

Mandible (Table 4; Figure 8A). Coxale toothed edge of pars incisiva has two large and 10 small smooth teeth. Distal tooth list slightly narrower with two large tusk-like teeth and 10 small smooth teeth. Proximal tooth list very narrow, with two large and five small teeth. Outer margin of toothed edge of basal endite with a large dagger-shaped tooth, a slightly smaller, rounded, tubular tooth and six subserrate triangular teeth. Two spinose setae are inserted laterally on the basal endite. Exopodite represented

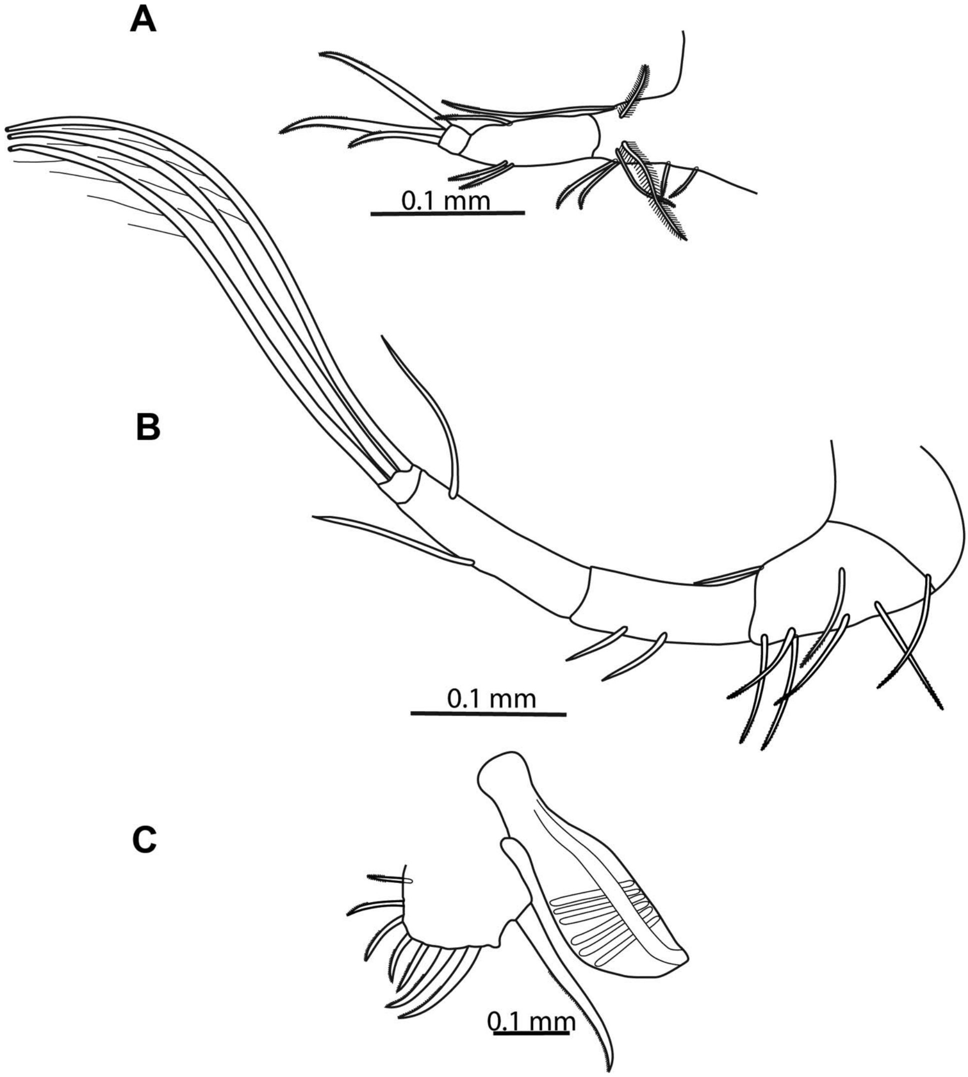


Figure 5. *Euconchoecia chierchiae* male: (A) fifth limb, (B) sixth limb, (C) caudal furca and intromittent organ.

by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with one short, bare, subterminal, dorsal seta and three finely spinose ventral setae. Second segment with one ventral and two dorsal setae all finely spinose. Third segment with seven spinose terminal setae, one very long and robust.

Maxilla (Table 4; Figure 8B). Basal segment with five anterior, one lateral and four posterior setae. Distal segment comparatively short and wide with six terminal claw setae, the posteriormost is longest, anterior claw with secondary spines.

Fifth limb (Table 5; Figure 8C). Ventrally basale with five (2+1+2) setae all with secondary spines, laterally two plumose setae, dorsally a single long dorsal spinose

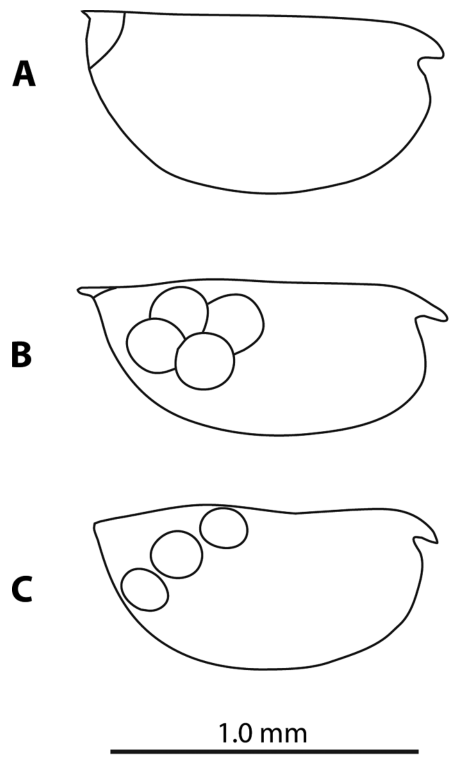


Figure 6. *Euconchoecia chierchiae*: (A) as drawn by Müller (1906) female 1.15–1.57 mm, (B) as drawn by Skogsberg (1920) female 1.10–1.30 mm, (C) as drawn by Angel (1993) female 1.08–1.30 mm.

seta – the remnant of the exopodite. First segment with two ventral setae and one dorsal seta, all spinose. Second segment with three unequal curved terminal claw setae of unequal length; middle claw the longest 6.0% CL.

Sixth limb (Table 5; Figure 8D). Basale with one proximal, two medial ventral spinose setae and a distal plumose seta, laterally a plumose seta and dorsally a terminal spinose seta. First endopodite segment with two ventral setae. Second segment with a single spinose seta both ventrally and dorsally. Third segment with three unequal, spinose terminal claw setae; longest middle claw 8.1% CL.

Caudal furca (Table 5; Figure 8E). Seven pairs of claw setae diminish in size dorsally; longest claw 14.1% CL. All have secondary spines along their trailing edges. Dorsal to the paired spines is a single seta with bilateral secondary spines. Between the first and second pair of claw setae is a verruciform process.

Male

Carapace (Figure 9A,B). Material deposited in the Natural History Museum contained two males. One measured 1.14 mm. The paralectotype (Table 6) with a length of 1.06 mm, height of 0.60 mm and breadth of 0.46 mm. Height : length ratio

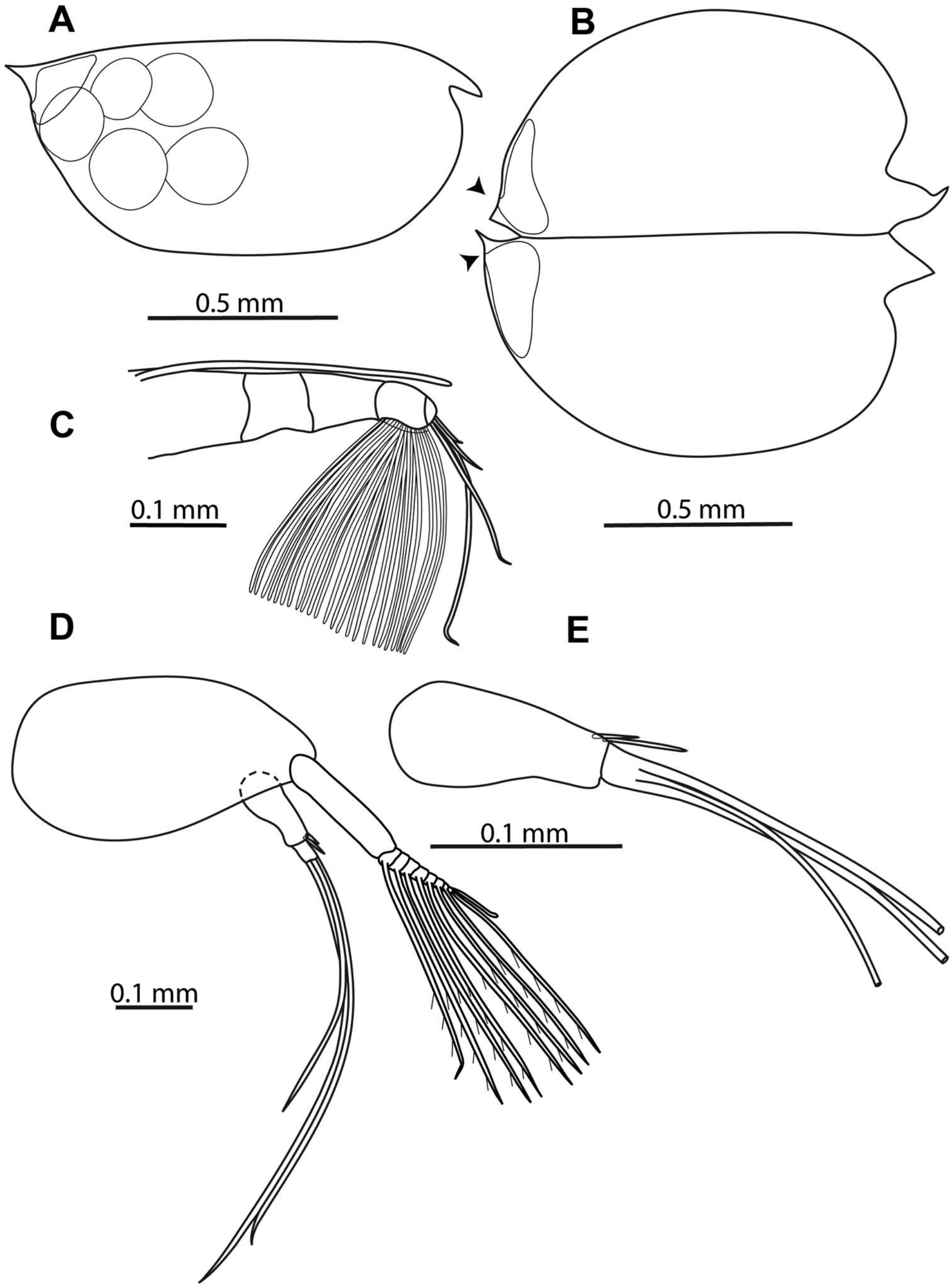


Figure 7. *Euconchoecia aculeata* female: (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ (D) second antenna viewed from inside, (E) endopodite viewed from inside.

56.6%, breadth : length ratio 43.4%. Carapace unsculptured. In lateral view maximum carapace height is just anterior to mid-length. Ventral margin curves uniformly. Dorsal margin curves upwards towards the rostral processes. Posterior dorsal corner

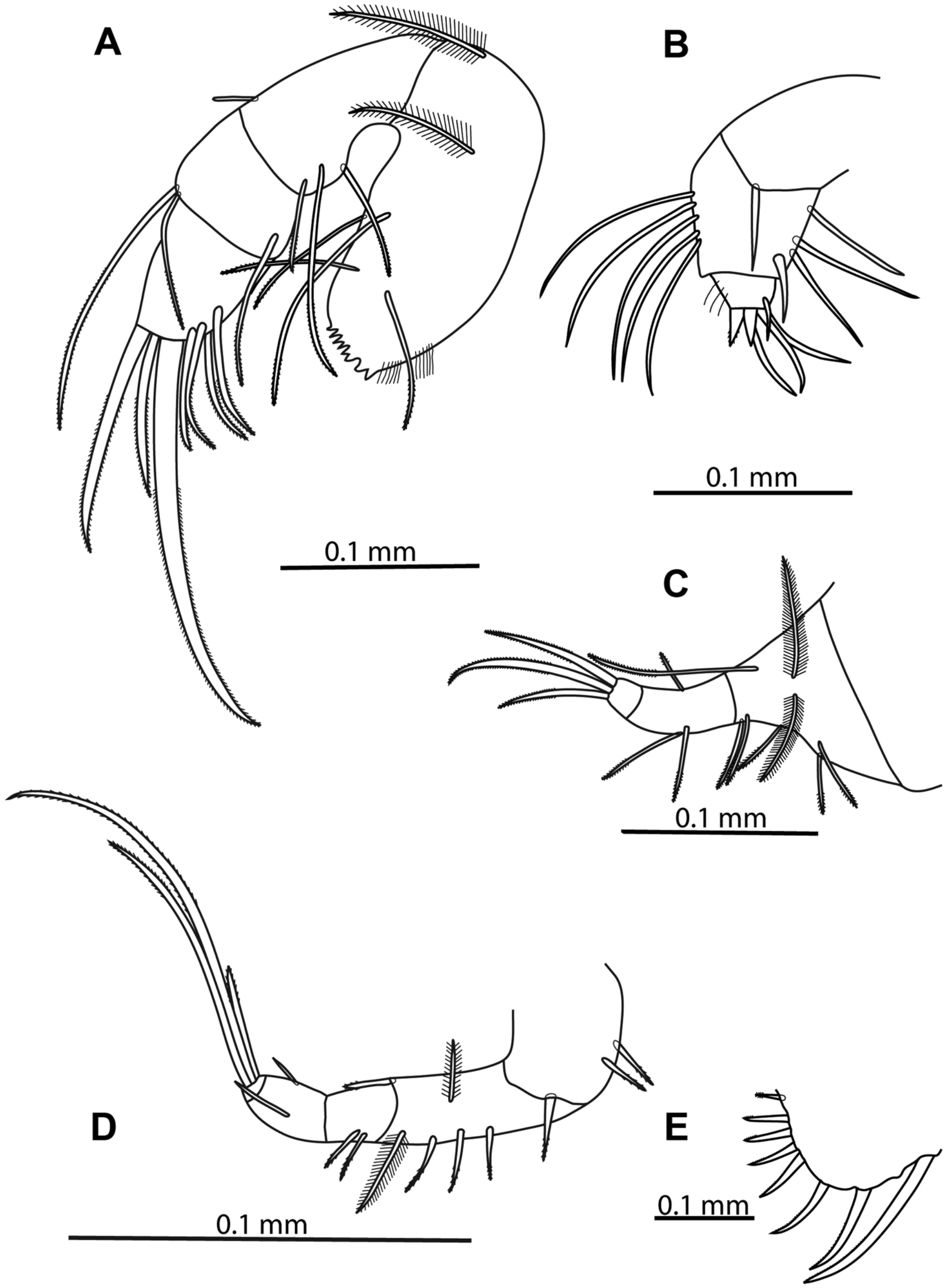


Figure 8. *Euconchoecia aculeata* female: (A) mandible, coxale not shown, (B) maxilla, (C) fifth limb, (D) sixth limb, (E) caudal furca.

of both valves furnished with a small spine. On the left valve the spine is slightly the smaller. Both rostra curve ventrally, the left rostrum is slightly smaller. The specimen was damaged, so measurements are imprecise. The "asymmetrical" glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal organ (Table 6; Figure 9C). Frontal organ fused into a single slender structure with rounded end that is shorter than A1 and 22.2% CL.

First antenna (Table 7; Figure 9C). With five well-defined segments. Fourth segment with ~ 24 thin walled bundle setae. All broken, so no measurements obtained. Fifth segment with five unequal setae. All broken, so no measurements obtained.

Second antenna (Table 7; Figure 9D). Protopodite 38.2% CL. Length of first exopodite segment approximately half prodopodite. Swimming setae shorter than the protopodite and all but the shortest have long hairs distally. Endopodite with short, pointed, bare a- and b- setae. There are no c-, d- or e-setae. The f-seta and g-seta respectively 36.8% CL and 38.4% CL. Right endopodite (Figure 9F) with an elongated clasping organ in the form of a hook with long proximal shank and curved end piece 1.7% CL. The h-seta is short 1.9% CL with long i-seta 16.0% CL. Left endopodite (Figure 9E) "hook" is reduced to basal shank with three setae terminally.

Mandible, maxilla (Table 8; Figure 10A,B). The full detailed structure of these limbs cannot be described because of the poor state of preservation of the material. Structure and arrangement of setae on the endopodite and the structure of the maxilla are same as female.

Fifth limb. Missing.

Sixth limb (Table 9; Figure 10C). Basale with five spinose setae ventrally, one lateral spinose seta and one bare dorsal seta. First endopodite segment with two ventral setae. Second endopodite segment with a single seta both ventrally and dorsally. Terminal setae broken.

Caudal furca (Table 9; Figure 10D). Structure and arrangement of the furcal claws is same as female. Longest claw is 17.5% CL.

Intromittent organ (Table 9; Figure 10E). The male copulatory appendage is exceptionally long, 27.4% CL.

Remarks

A full and detailed description of the type material is given here because the original description is so incomplete that it has undoubtedly led to confusion in the subsequent literature. By unambiguously describing all its characters, even when very similar, if not identical, to those described above for *E. chierchiae*, confusion should be avoided in future.

Scott's original description of this species as *Halocypris aculeata* (Scott 1894) was vague and incomplete. Cleve (1905), with approval from Scott, transferred this species to the genus *Euconchoecia*, because Scott's specimens were clearly not *Halocypris*, and

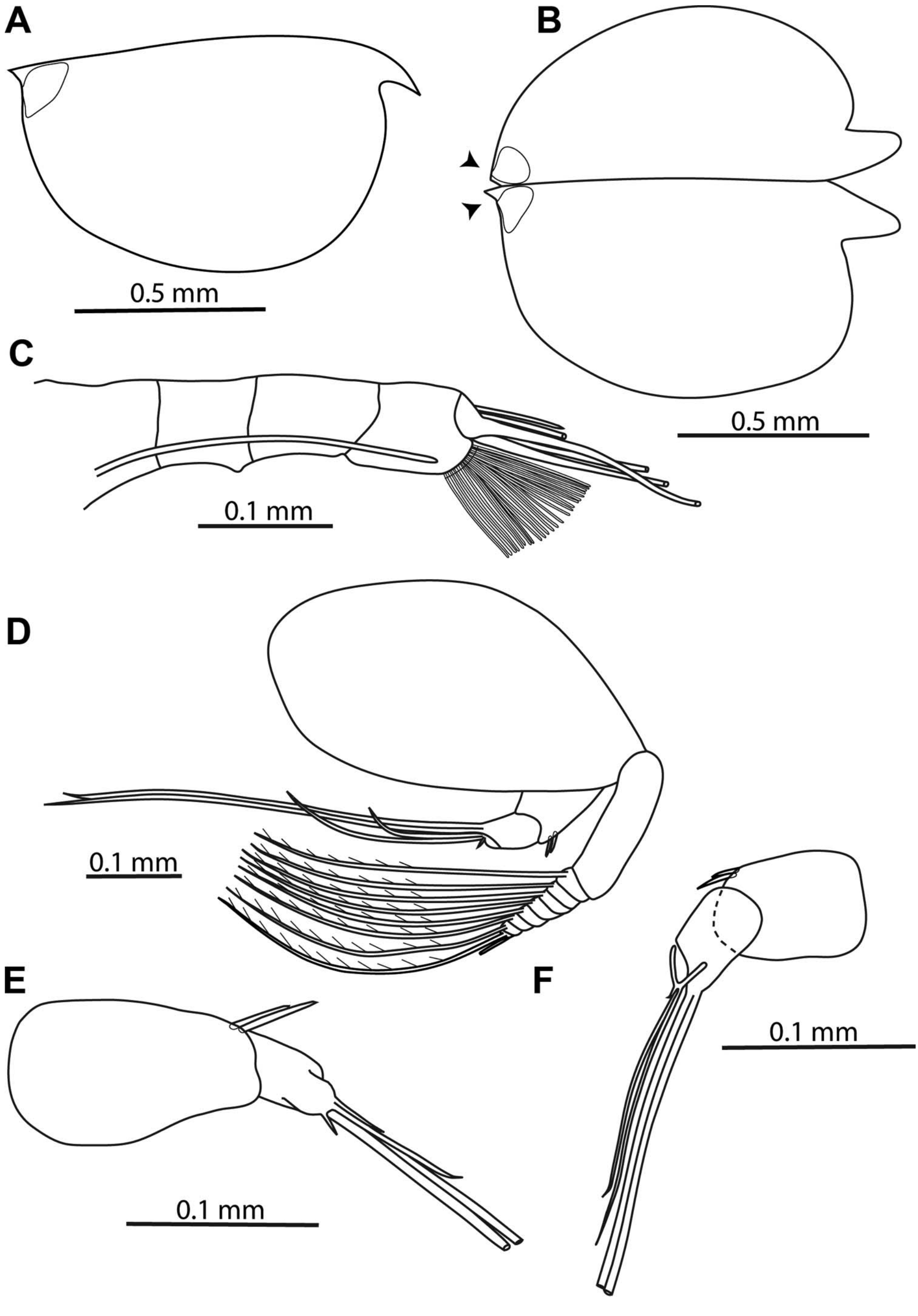


Figure 9. *Euconchoecia aculeata* male: (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside, (E) left endopodite viewed from inside, (F) right endopodite viewed from inside.

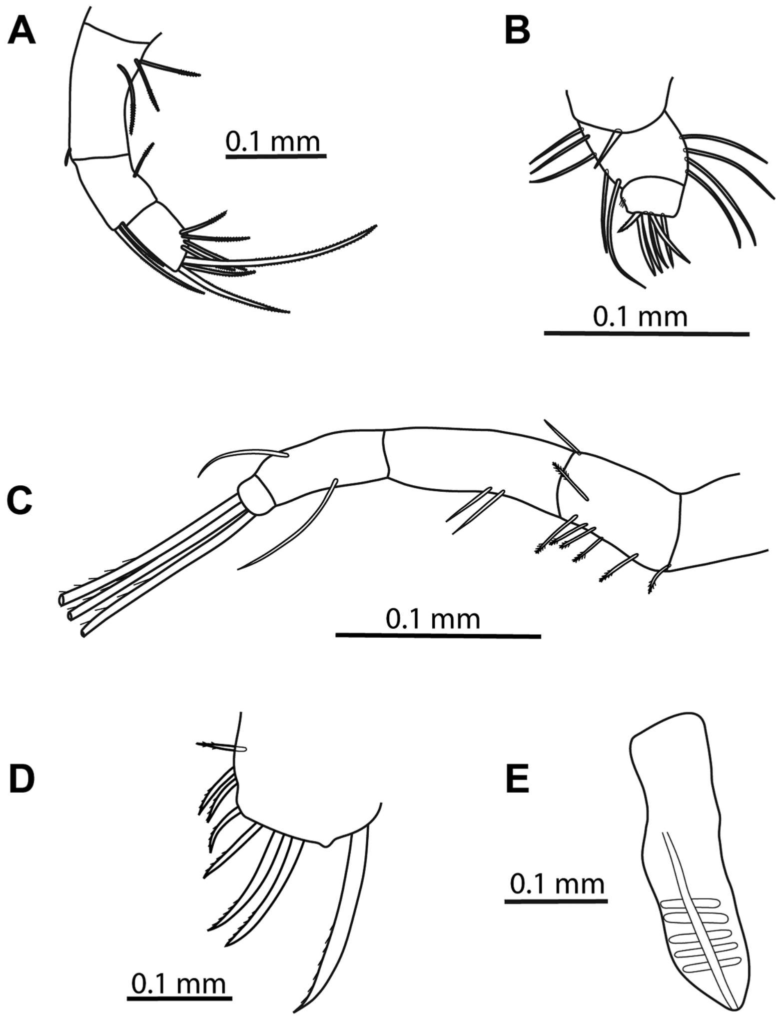


Figure 10. *Euconchoecia aculeata* male: (A) mandible, coxale not shown, (B) maxilla, (C) sixth limb, (D) caudal furca, (E) intromittent organ.

Müller had described his new genus *Euconchoecia.* The description of *E. aculeata* by Müller (1912) records a length of 0.9–1.05 mm for females and 0.95 mm for males. This is smaller than the type specimens deposited by Scott at the Natural History Museum, London. Poulsen (1969) and Tseng (1969) both reported *E. aculeata* from various locations outside the Atlantic without re-examining Scott's material. Given the inadequate quality of the original description, subsequent records of *E. aculeata* remote from the type locality require confirmation.

The species *E. aculeata* is very similar to *E. chierchiae* and both are of similar size. The female of *E. aculeata* is more elongate and the rostrum is narrower and more downward pointing in both sexes (Figure 21). The frontal organ of female *E. aculeata* is marginally longer than the first antenna (Table 2), and in the male the second antenna right clasper shank length is very much smaller than that of *E. chierchiae* (Table 7). These characters readily distinguish these two species.

Euconchoecia omanensis sp.nov.
(Figures 11–15, 21E,F)

Type material

Permanent preparations of the dissected holotype and allotype used in this description are deposited at the Natural History Museum, London registration number BMNH 2009.330 for the holotype (female) and BMNH 2009.331 for the allotype (male). Registration numbers BMNH 2009.332–341 are for the remaining female and male paratypes retained in 80% ethyl alcohol.

Etymology

The specific name refers to the type locality of the Gulf of Oman.

Description

The meristic characters of the carapaces of males and females, and the frontal organs, first and second antennae, mouthparts and limbs are listed in Tables 2 to 9 together with comparative data for the other species described here.

Female

Carapace (Figure 11A,B). Mean length measured 1.42 ± 0.06 mm ($n = 100$). Carapace of holotype (Table 2) with a length of 1.42 mm, a height of 0.46 mm and a breadth of 0.40 mm. Height : length ratio 32.4%, breadth : length ratio 28.2%. Carapace is unsculptured. In lateral view elongate: maximum height is just anterior to mid-length. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a spine. Spine much smaller on left valve. Dorsal margin arcs anteriorly up towards dorsal end of hinge between carapace valves. Both rostra narrow and point forward, the left rostral process longer and more pointed. The 'asymmetrical' glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal organ (Table 2; Figure 11C). Frontal organ fused into a slender structure with rounded end, that is significantly longer than A1 and 18.7% CL.

First antenna (Table 3; Figure 11C). With five segments, but the suture between fourth and fifth segments ill-defined. Limb length is $\sim$ 35% CL. Fourth segment with $\sim$ 24 thin walled bundle setae all 9.2% CL. Fifth segment with four more unequal setae, a-seta quite short 2.1% CL; b-seta 3.5% CL; c-seta 10.0% CL; d-seta 7.7% CL.

Second antenna (Table 3; Figure 11D). Protopodite is 24.6% CL. Length of first exopodite segment is approximately half protopodite. Most swimming setae are similar in length to protopodite, all but the shortest terminal seta have long hairs distally.

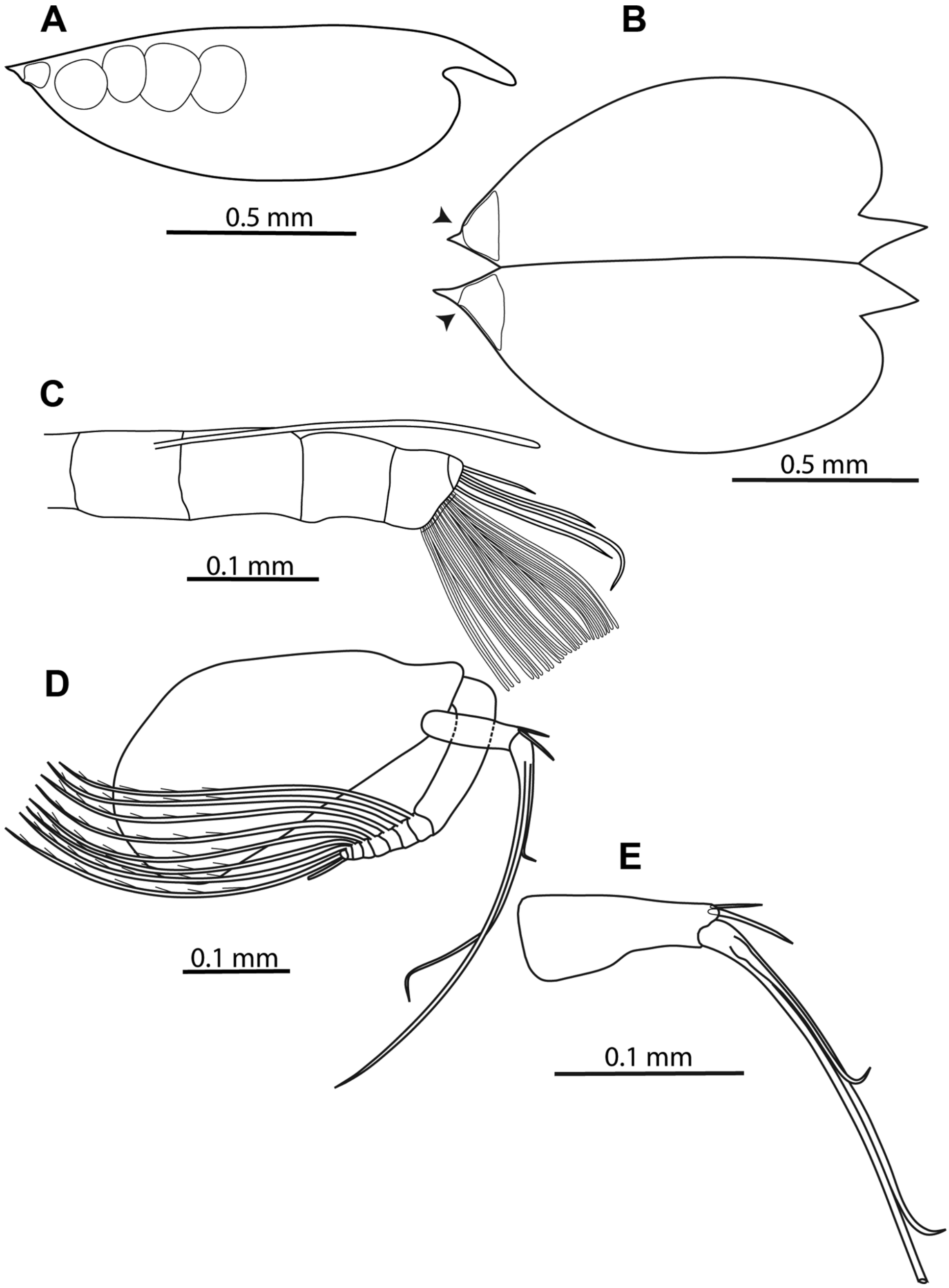


Figure 11. *Euconchoecia omanensis* female: (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside, (E) endopodite viewed from inside.

Endopodite (Figure 11E) with short, pointed, bare a- and b-setae. There are no c-, d- or e-setae. The f- and g-setae, respectively, 17.8% CL and 23.2% CL. The i-seta is 7.2% CL, but h- and j-setae are absent.

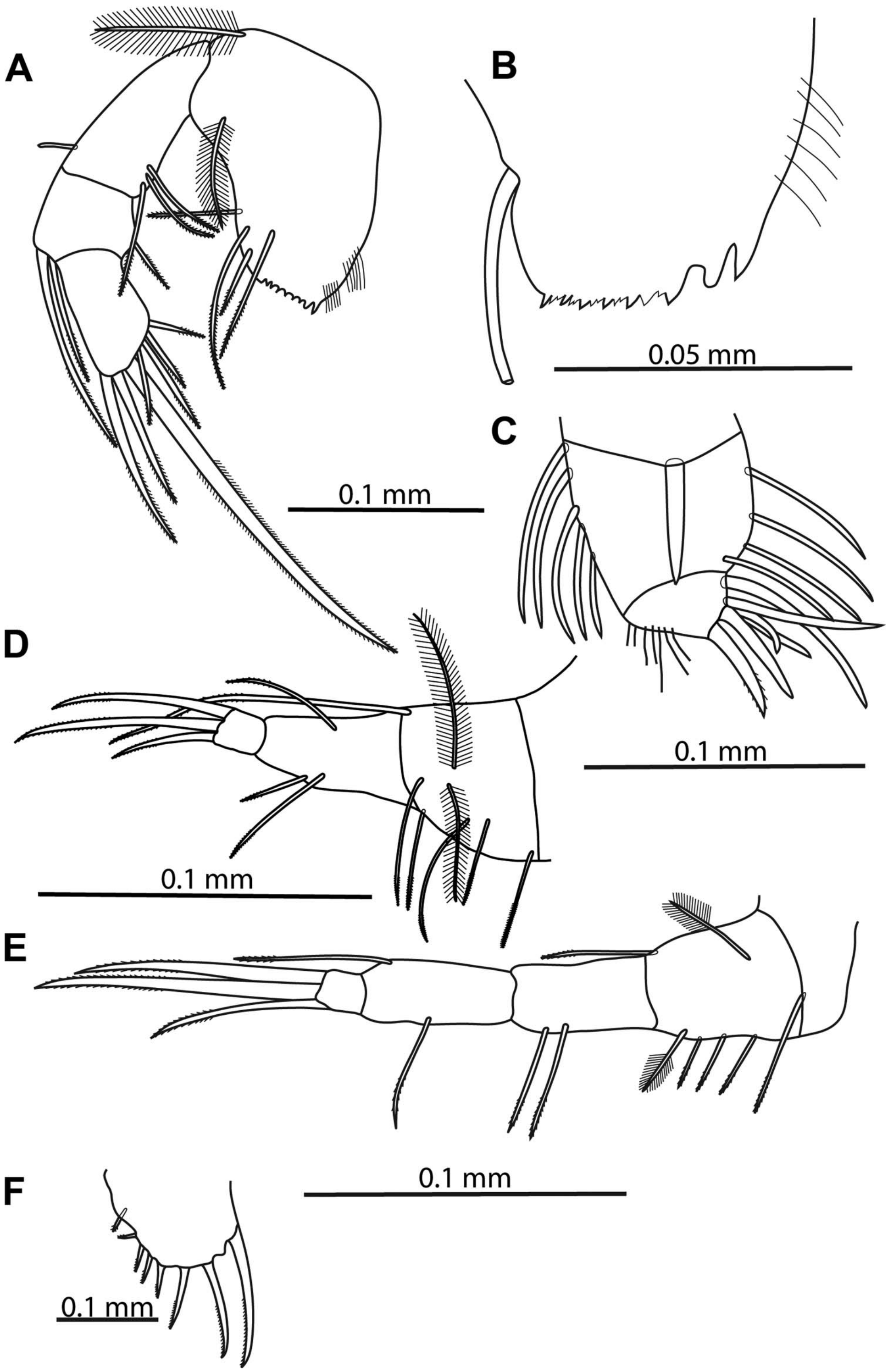


Figure 12. *Euconchoecia omanensis* female: (A) mandible, coxale not shown, (B) basal endite of mandible, (C) maxilla, (D) fifth limb, (E) sixth limb, (F) caudal furca.

Mandible (Table 4; Figure 12A,B). Coxale toothed edge of pars incisiva has two large and 10 small smooth teeth. Distal tooth list slightly narrower with two large tusk-like teeth and 10 small smooth teeth. Proximal tooth list very narrow, with two large and five small teeth. Outer margin of toothed edge of basal endite with a large dagger-shaped tooth, a slightly smaller, rounded, tubular tooth and six subserrate teeth. Two spinose setae are inserted laterally on basal endite. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with one short, bare, subterminal dorsal seta and three finely spinose ventral setae. Second segment with one ventral and two dorsal setae all finely spinose. Third segment with seven spinose terminal setae, one very long and robust.

Maxilla (Table 4; Figure 12C). Basal segment with five anterior, one lateral and four posterior setae. Distal segment comparatively short and wide, with six terminal claw setae, the posteriormost is longest, anterior claw with secondary spines.

Fifth limb (Table 5; Figure 12D). Ventrally basale with five (2+1+2) setae all with secondary spines, laterally two plumose setae, dorsally a single long spinose seta. First segment with two ventral setae and one dorsal seta, all spinose. Second segment with three unequal curved terminal claw setae; middle claw the longest and is 4.1% CL.

Sixth limb (Table 5; Figure 12E). Basale with one proximal, two medial ventral spinose setae and a distal plumose seta, laterally a plumose seta and dorsally a terminal spinose exopodal seta. The first endopodite segment with two ventral setae. Second segment with a single spinose seta both ventrally and dorsally. Third segment with three unequal spinose terminal claw setae; longest middle claw is 7.1% CL.

Caudal furca (Table 5; Figure 12F). Seven pairs of claw setae diminish in size dorsally; longest claw 10.4% CL. All have secondary spines along their trailing edge. Dorsal to the paired spines is a single seta with bilateral secondary spines. Between first and second pair of claw setae is a verruciform process.

Male

Carapace (Figure 13A,B). Mean length measured 1.15 ± 0.04 mm ($n = 100$). Carapace of allotype (Table 6) with length of 1.20 mm, a height of 0.44 mm and breadth of 0.40 mm. Height : length ratio 36.7%, breadth : length ratio 33.3%. Carapace unsculptured. Maximum carapace height just anterior to mid-length. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a small spine. On the left valve the spine is smaller. The dorsal margin arcs anteriorly up towards dorsal end of hinge between carapace valves. Both rostra broad, curve ventrally, the left rostral process is longer. The "asymmetrical" glands open at a similar height on the posterior margin of each valve just below the spine at posterior dorsal corner.

Frontal organ (Table 6; Figure 13C). Frontal organ fused into a single slender structure with a rounded end that is significantly longer than A1 and 31.3% CL.

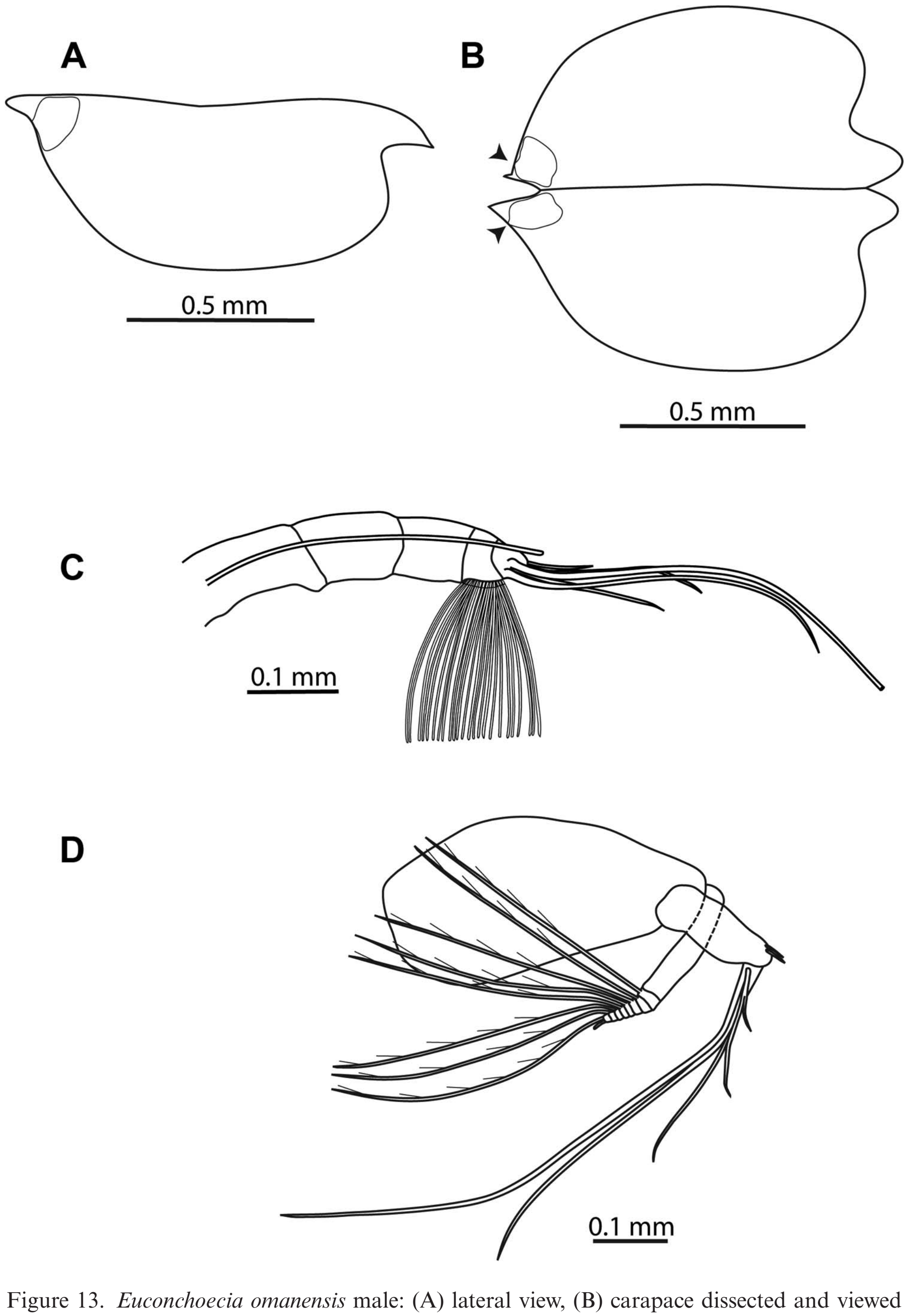


Figure 13. *Euconchoecia omanensis* male: (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) frontal organ and first antenna, (D) second antenna viewed from inside.

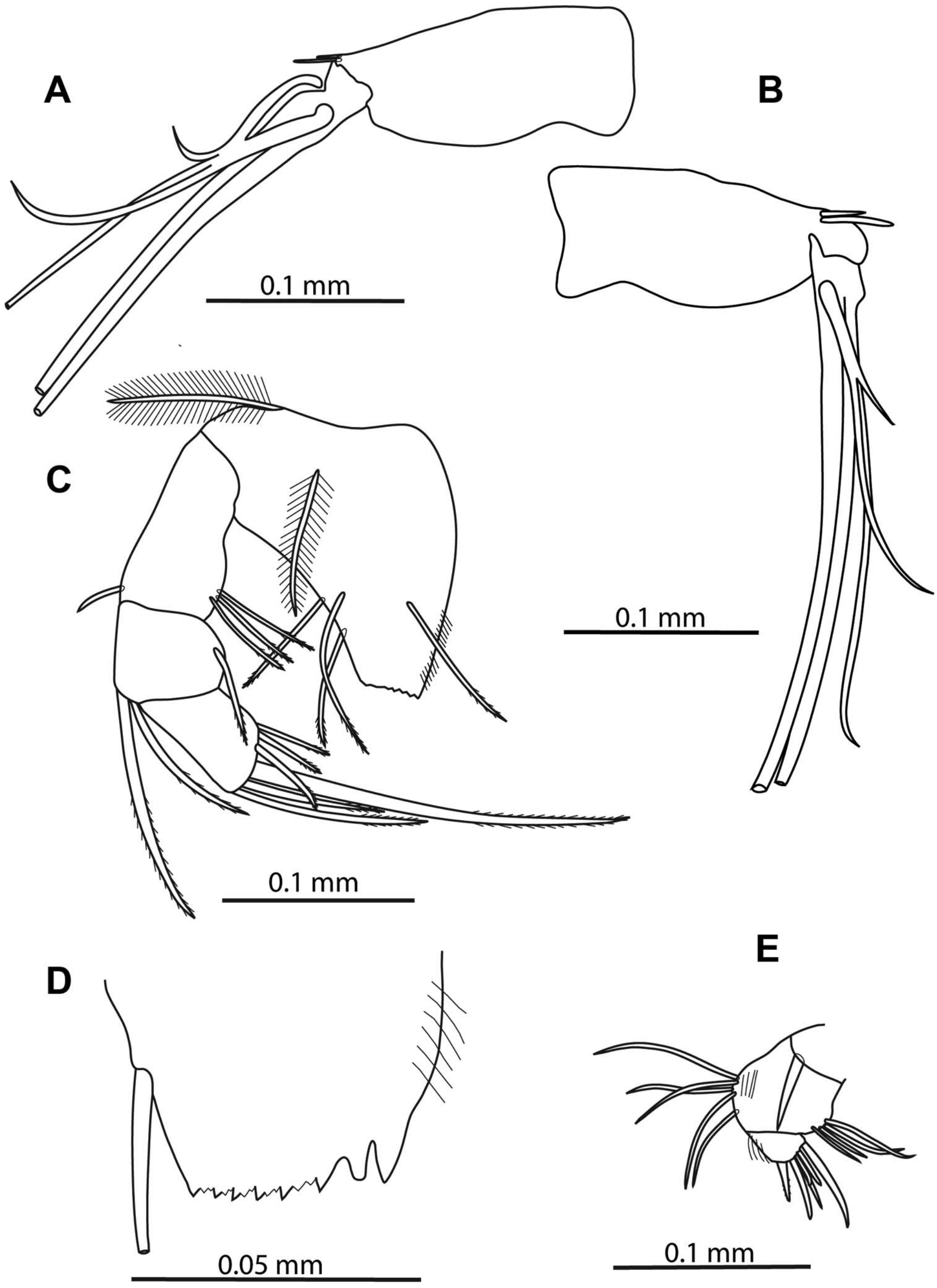


Figure 14. *Euconchoecia omanensis* male: (A) right endopodite viewed from inside, (B) left endopodite viewed from inside, (C) mandible, coxale not shown, (D) basal endite of mandible, (E) maxilla.

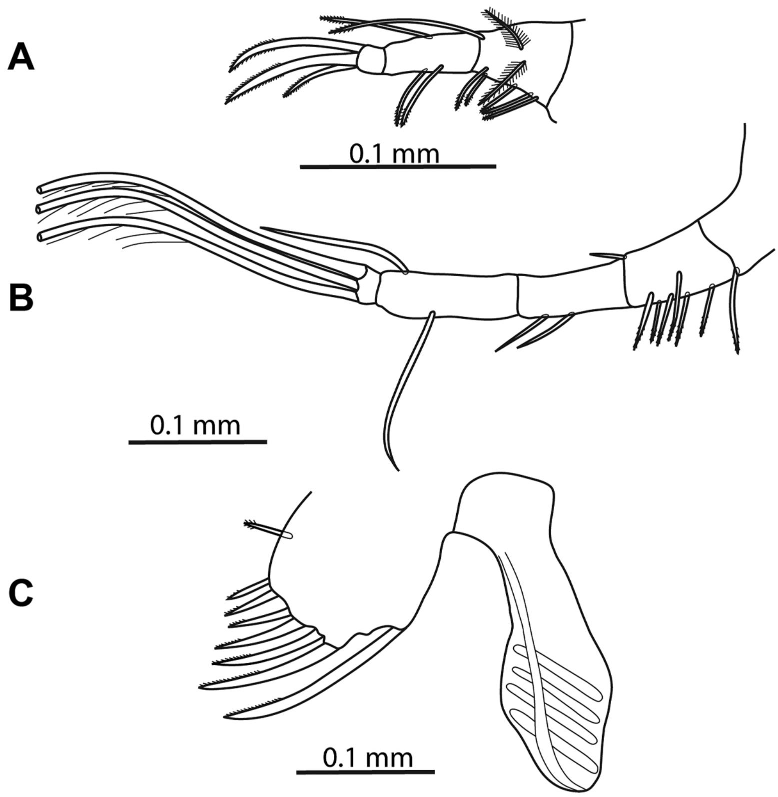


Figure 15. *Euconchoecia omanensis* male: (A) fifth limb, (B) sixth limb, (C) caudal furca and intromittent organ.

First antenna (Table 7; Figure 13C). With five well-defined segments. Limb length ~ 35% CL. Fourth segment with ~ 24 thin walled bundle setae all 14.4% CL. Fifth segment with five more unequal setae: a-seta 8.8% CL; b-seta 15.0% CL; c-seta 18.3% CL; d-seta 32.1% CL; e-seta 46.3% CL.

Second antenna (Table 7; Figure 13D). Protopodite 37.1% CL. Length of first exopodite segment approximately third of protopodite. Most swimming setae similar in length to protopodite, all but the shortest have long hairs distally. Endopodite with short, pointed, bare a- and b-setae. There are no c-, d- or e-setae. The f-seta, very long, g-seta, respectively, 39.2% CL and 60.0% CL. Right endopodite (Figure 14A) with elongated clasping organ in form of hook with a long proximal shank and very long curved end piece 5.4% CL. The h-seta is short and curved 2.9% CL; i-seta 19.2% CL; j-seta 9.6% CL. Left endopodite (Figure 14B) the hook reduced to just basal shank with three setae terminally.

Mandible, maxilla, fifth limb (Tables 8, 9; Figure 14C–E, 15A). Structure and arrangement of setae of mandible, maxilla and fifth limb are same as female.

Sixth limb (Table 9; Figure 15B). Basale with five spinose setae, one lateral spinose seta and one bare dorsal exopodal seta. First segment with two ventral setae. Second segment with a single bare seta both ventrally and dorsally. Third segment with three very long subequal terminal setae, with long hairs distally 30.4% CL.

Caudal furca (Table 9; Figure 15C). Structure and arrangement of claws same as female. Longest claw 12.5% CL.

Intromittent organ (Table 9; Figure 15C). Male copulatory appendage long 19.6% CL.

Remarks

Euconchoecia omanensis should be regarded as a separate species on the basis of the following combination of characters: both females and males are more elongate than *E. chierchiae* and *E. aculeata*; the height : length ratio of *E. omanensis* was 32.4% and the breadth : length ratio was 28.2%; the spines on the posterior dorsal corner of the female were almost twice the length of the spines of *E. chierchiae*, and in the male the left spine on the posterior dorsal corner was 2% longer and the right spine was 3% longer. In both sexes the frontal organ reached well beyond the first antenna and on the second antenna the right clasper shank length was significantly smaller than in *E. chierchiae*, but longer than in *E. aculeata*.

Euconchoecia hormuzensis sp. nov.
(Figures 16–20, 21G,H)

Type material

Permanent preparations of the dissected holotype and allotype used in this description are deposited at the Natural History Museum, London, registration number BMNH 2009.342 for the holotype (female) and BMNH 2009.343 for the allotype (male). Registration numbers BMNH 2009.344–353 are for the 48 female and 36 male paratypes retained in 80% ethyl alcohol.

Etymology

The specific name refers to the type locality close to the Gulf of Hormuz.

Description

The meristic characters of the carapaces of males and females, and the frontal organs, first and second antennae, mouthparts and limbs are listed in Tables 2 to 9 together with comparative data for the other species described here.

Female

Carapace (Figure 16A,B). Mean length measured 1.04 ± 0.05 mm ($n = 48$). Carapace of holotype (Table 2) with length 1.00 mm, height 0.42 mm and breadth 0.40 mm.

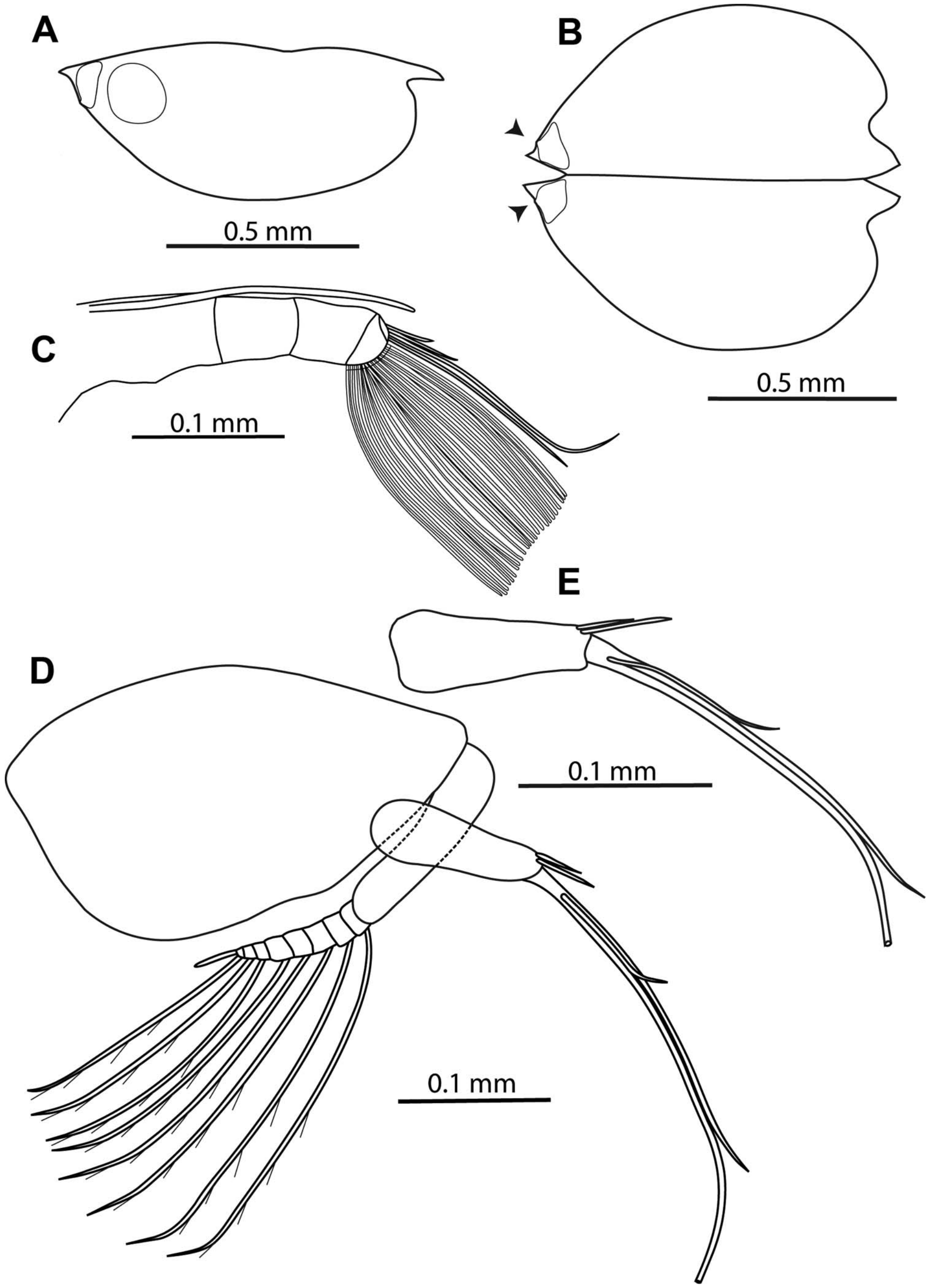


Figure 16. *Euconchoecia hormuzensis* female: (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside, (E) endopodite viewed from inside.

Height : length ratio 42.0%, breadth : length ratio of 40.0%. Carapace unsculptured. In lateral view slightly elongate: maximum height just anterior to mid-length. Ventral margin curves smoothly. Posterior dorsal corner of both valves furnished with a small spine. Spine slightly smaller on left valve. Dorsal margin arcs anteriorly up towards dorsal end of hinge between carapace valves. Both rostra curve ventrally and are of the same length. The "asymmetrical" glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal organ (Table 2; Figure 16C). Frontal organ fused into a single slender structure with a rounded end that is slightly longer than A1 and 20.3% CL.

First antenna (Table 3; Figure 16C). With five segments, but suture between fourth and fifth segment ill-defined. Limb length is ~ 37% CL. Fourth segment with ~ 24 thin walled bundle setae all 16.3% CL. Fifth segment with four more setae of different lengths; a-seta quite short 3.8% CL; b-seta 5.5% CL; c-seta 17.0% CL; d-seta 13.5% CL.

Second antenna (Table 3; Figure 16D). Protopodite 30% CL. Length of first exopodite segment approximately half length of protopodite. Swimming setae shorter in length than protopodite, all but shortest have long hairs distally. Endopodite (Figure 16E) with short, pointed, bare a- and b-setae. There are no c-, d- or e-setae. The f- and g-setae respectively 24.0% CL and 43.5% CL. The i-seta is long 11.5% CL, but h- and j-setae are absent.

Mandible (Table 4; Figure 17A,B). Coxale toothed edge of pars incisiva has two large and 10 small smooth teeth. Distal tooth list narrower with two large tusk-like teeth and 10 small smooth teeth. Proximal tooth list very narrow, with two large and five small teeth. Outer margin of toothed edge of basal endite with a large dagger-shaped tooth, a slightly smaller, rounded, tubular tooth and six subserrate triangular teeth. Two spinose setae are inserted laterally on basal endite. Exopodite represented by moderately long plumose seta of moderate length inserted on outer margin of basis. First endopodite segment with one short, bare, subterminal, dorsal seta and three finely spinose ventral setae. Second segment with one ventral and two dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla (Table 4; Figure 17C). Basal segment with five anterior, one lateral and four posterior setae. Distal segment comparatively short and wide with six terminal claw setae; the posteriormost is longest; anterior claw with secondary spines.

Fifth limb (Table 5; Figure 17D). Ventrally basale with five (2+1+2) setae all with secondary spines; laterally plumose setae, dorsally a single long spinose seta – the remnant of the exopodite. First segment with two ventral setae and one dorsal seta, all spinose. Second segment with three unequal spinose, terminal claw setae; longest middle claw 5.5% CL.

Sixth limb (Table 5, Figure 17E). Basale with one proximal, two medial ventral spinose setae and a distal plumose seta, laterally a plumose seta and dorsally a terminal

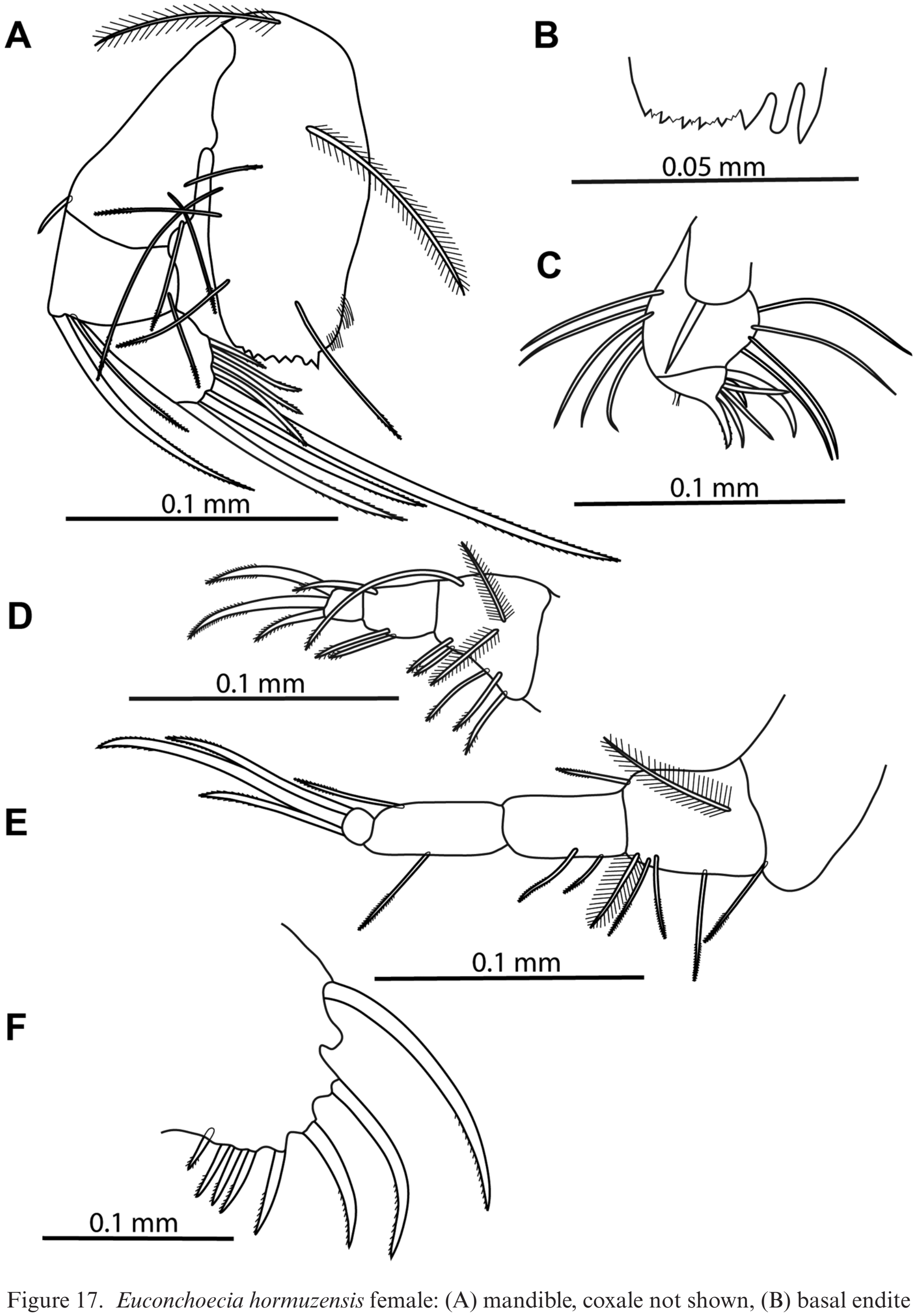


Figure 17. *Euconchoecia hormuzensis* female: (A) mandible, coxale not shown, (B) basal endite of mandible, (C) maxilla, (D) fifth limb, (E) sixth limb, (F) caudal furca.

spinose exopodal seta. First endopodite segment with two ventral setae. Second segment with a single spinose seta both ventrally and dorsally. Third segment with three unequal spinose, terminal claw setae; longest middle claw 8.5% CL.

Caudal furca (Table 5; Figure 17F). Seven pairs of claw setae diminish in size dorsally; longest claw 12.0% CL. All have secondary spines along the trailing edges. Dorsal to the paired spines is a small unpaired seta with bilateral secondary spines. Between the first and second pair of claw setae is a verruciform process.

Male

Carapace (Figure 18A,B). Mean length measured 1.00 ± 0.03 mm ($n = 36$). Allotype (Table 6) with length of 0.98 mm, a height of 0.40 mm and breadth of 0.40 mm. Height : length ratio 40.8%, breadth : length ratio 40.8%. Carapace unsculptured. In lateral view maximum height just anterior to mid-length. Ventral margin curves smoothly into posterior margin. Posterior dorsal corner of both valves furnished with a small spine. On the left valve the spine is slightly smaller. Dorsal margin arcs anteriorly up towards carapace hinge between carapace valves. Both rostra curve ventrally, the left is the longer and more pointed. The "asymmetrical" glands open at a similar height on posterior margin of each valve just below spine at posterior dorsal corner.

Frontal organ (Table 6, Figure 18C). Frontal organ fused into a single slender structure with a rounded end that is slightly longer than A1 and 21.1% CL.

First antenna (Table 7; Figure 18C). With five well-defined segments. Limb length ~ 34% CL. Fourth segment with ~ 24 thin walled bundle setae all 17.1% CL. Fifth segment with five more setae; a-seta 3.7% CL; b-seta 4.6% CL; c-seta 13.8% CL; d-seta 34.2% CL; e-seta 50.0% CL.

Second antenna (Table 7; Figure 18D). Protopodite 40.8% CL. Length of first exopodite segment 15.3% CL approximately third protopodite. Most swimming setae are about two-thirds the length of protopodite, all but shortest have long hairs distally. Endopodite with short, pointed, bare a- and b-setae. There a no c-, d- or e-setae. The f-seta and g-seta respectively 39.8% CL and 119.9% CL. Right endopodite (Figure 19B) with elongated clasping organ in form of hook with a long proximal shank and long curved end piece 6.4% CL. The h-seta is short and curved 2.8% CL; the i-seta 20.7% CL; j-seta 9.7% CL. Left endopodite (Figure 19A) "hook" reduced to just basal shank with three setae terminally.

Mandible, maxilla, fifth limb (Tables 8, 9; Figure 19C,D,E,20A). Mandible, maxilla and fifth limb structure and arrangement of setae are same as female.

Sixth limb (Table 9; Figure 20B). Basale with five spinose setae, one lateral spinose seta and one bare dorsal exopodal seta. First segment with two ventral setae. Second segment with a single bare seta both ventrally and dorsally. Third segment with three subequal terminal setae, all very long, evenly curved with long hairs distally 34.7% CL.

Caudal furca (Table 9; Figure 20C). Structure and arrangement of the furcal claws are same as female; longest claw 14.5% CL.

Intromittent organ (Table 9; Figure 20C). The male copulatory appendage is long, 20.9 % CL.

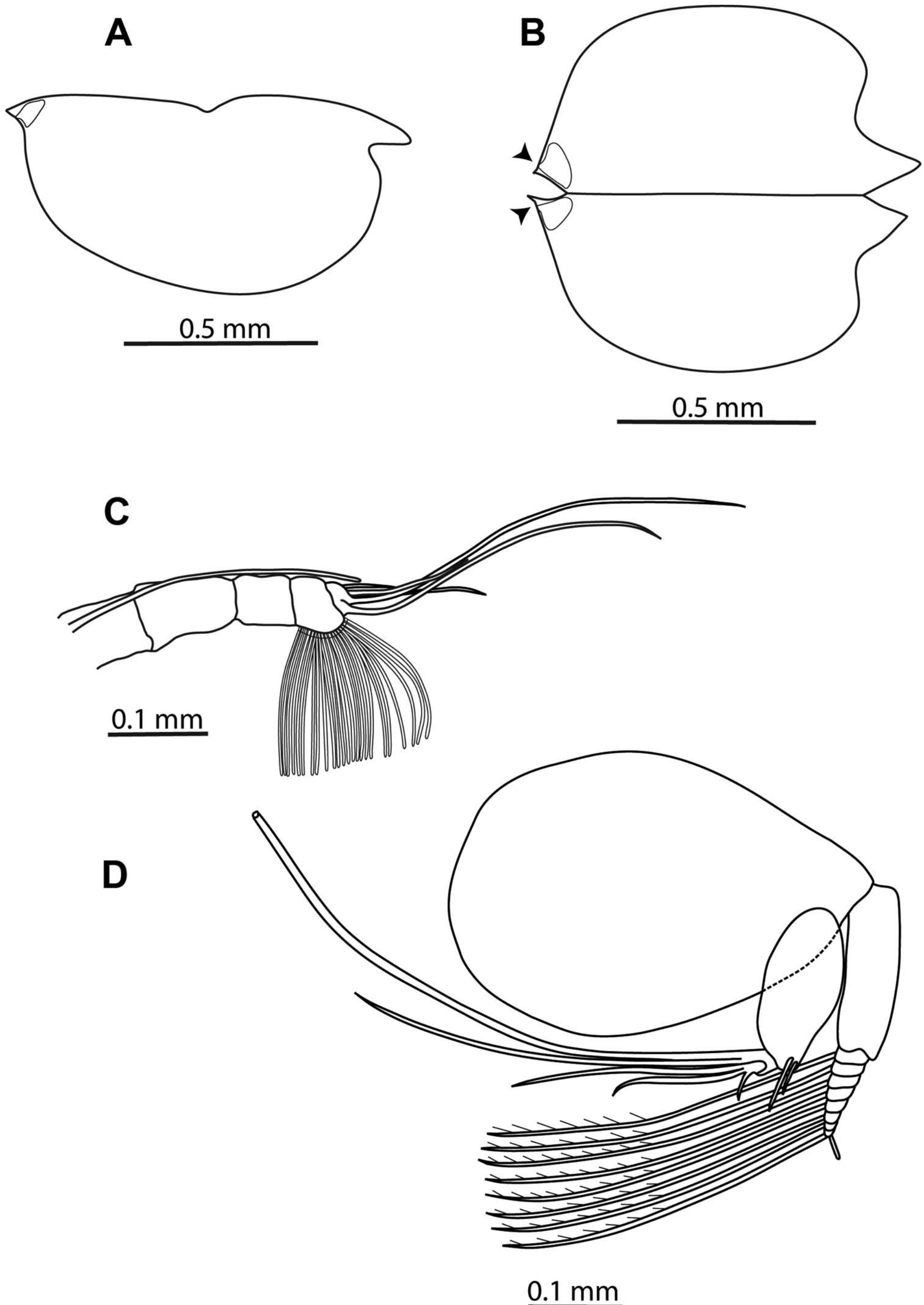


Figure 18. *Euconchoecia hormuzensis* male: (A) lateral view, (B) carapace dissected and viewed dorsally – arrows indicate gland openings, (C) first antenna and frontal organ, (D) second antenna viewed from inside.

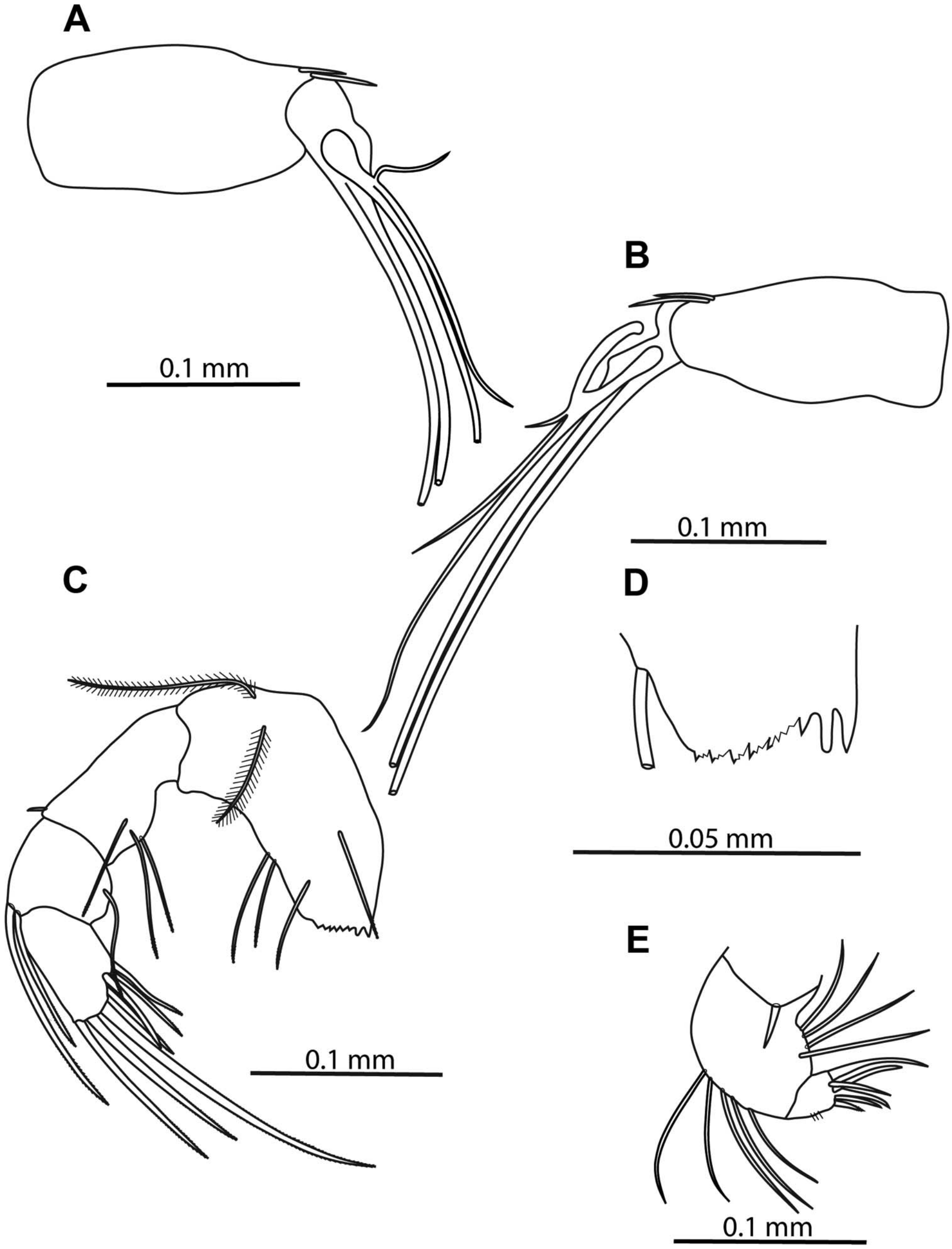


Figure 19. *Euconchoecia hormuzensis* male: (A) left endopodite viewed from inside, (B) right endopodite viewed from inside, (C) mandible, coxale not shown, (D) basal endite of mandible, (E) maxilla.

Remarks

Euconchoecia hormuzensis may be regarded as a separate species on the basis of both sexes being markedly smaller in length, breadth and height than the other

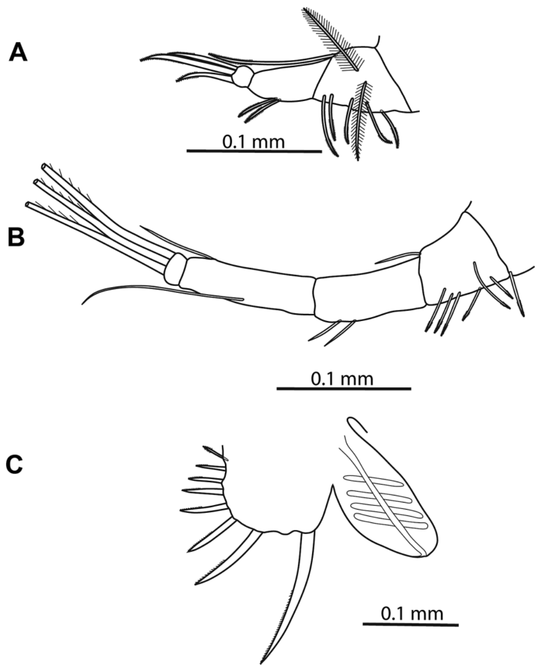


Figure 20. *Euconchoecia hormuzensis* male: (A) fifth limb, (B) sixth limb, (C) caudal furca and intermittent organ.

three species; the height : length ratio in both sexes is approximately 40% and the breadth : length ratio in both sexes is approximately 40%. The spines on the posterior dorsal corner are similar in length and the rostral processes are quite short. The frontal organ is marginally longer than the first antenna in both sexes, whereas in *E. chierchiae* the frontal organ is shorter and in *E. aculeata* it is marginally longer in the female, but shorter in the male. In *E. omanensis* the frontal organ is significantly longer than the first antenna in both sexes. On the second antenna the right shank length, at 6.4%, is greater than the shank length of *E. aculeata* and *E*. *omanensis*, but less than the shank length of *E. chierchiae*. These differences are sufficient to justify the establishment of a new species.

Discussion

Detailed examination of four *Euconchoecia* species reveals substantial differences between them. The length of the carapace, and the height : length ratio of the carapace varies significantly between all four species (Tables 2, 6; Figure 21). Although each species bears spines on the posterior dorsal corner, the length of spine on each valve is species specific (Tables 2, 6). The rostrum size and shape are important species-level differences (Figure 21). There are also clear differences between the four species in the length of the frontal organs relative to the length of the first antenna in both sexes (Tables 2, 6). The male and female frontal organs of *E. omanensis* are particularly long, whereas those of *E. chierchiae* are shorter than the antenna in both sexes.

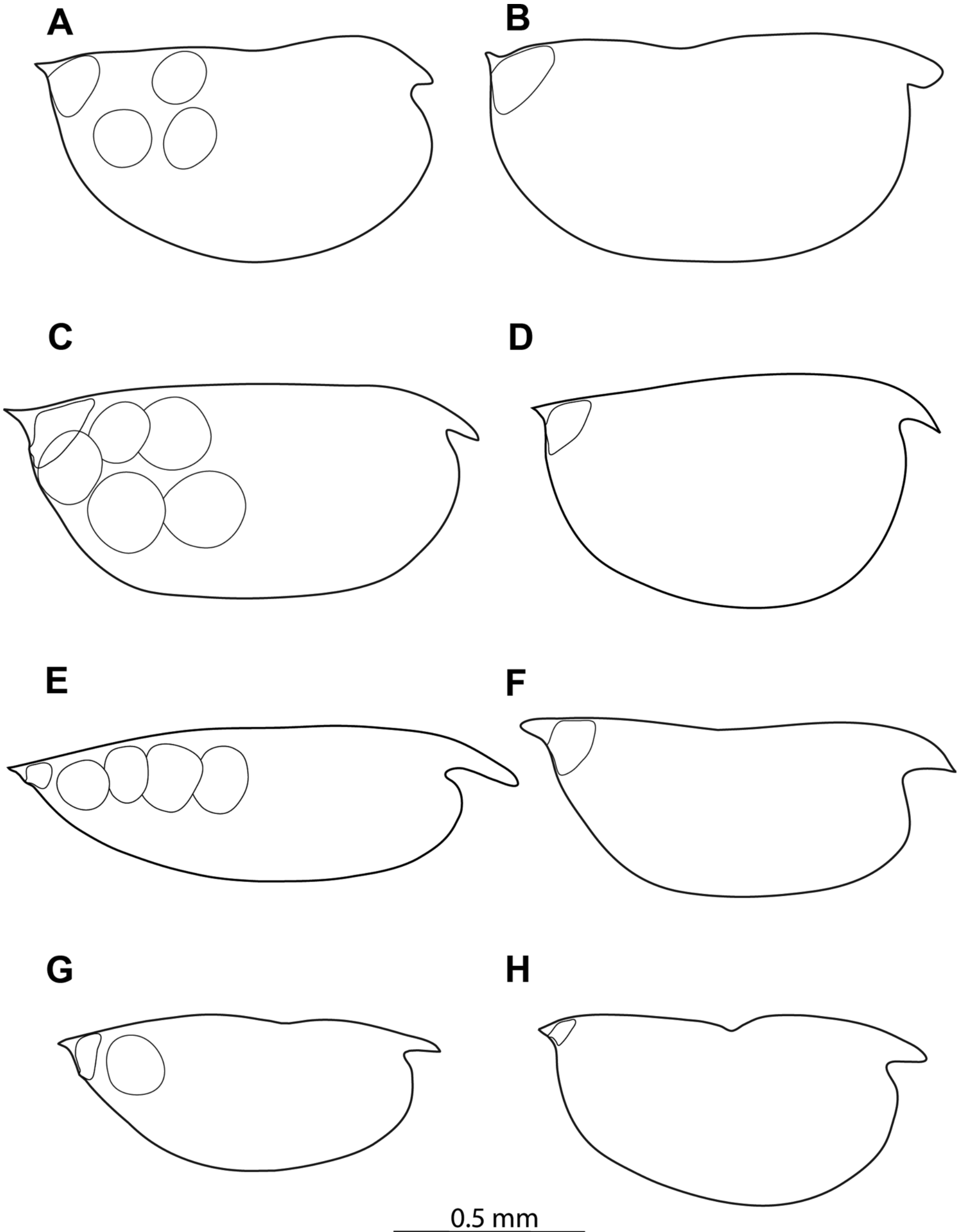


Figure 21. *Euconchoecia*. (A) *E. chierchiae* female, (B). *E. chierchiae* male, (C) *E. aculeata* female, (D) *E. aculeata* male, (E) *E. omanensis* female, (F) *E. omanensis* male, (G) *E. hormuzensis* female, (H) *E. hormuzensis* male, all viewed laterally.

There are clear differences in size of the protopodite of the second antenna between the sexes, although not between species (Tables 3, 7). In the males there is a marked disparity between the left and right endopodites. The right endopodite bears an elongated clasping organ in the form of a hook with a long proximal shank. The shank length, however, varies considerably between species (Table 7). There were no other interspecific differences.

There is some uncertainty in the literature regarding the number of spines on the caudal furca in some *Euconchoecia* species. Tseng (1969) in describing *Euconchoecia elongata* illustrated seven pairs of spines, but when describing the developmental stages of this species Tseng (1975) recorded eight pairs of spines on the caudal furca. Poulsen (1969) for the generic diagnosis of *Euconchoecia* stated that the number of spines on the caudal furca is the same as for *Bathyconchoecia* Deevey (1968), namely eight pairs, but in describing *E. chierchiae* and *E. aculeata* he refers to Skogsberg (1920) who described seven pairs with a verruciform process between the first and second spines. All four species examined in this paper have seven pairs of spines with a verruciform process between the first and second spines.

All species of *Euconchoecia* have been collected from near surface coastal waters with an oceanic influence. *Euconchoecia chierchiae* has been identified in the Pacific, Atlantic and Indian Oceans, and has been regarded as a ubiquitous species, although no exact data on abundances are available as few have been recorded in oceanic waters. Poulsen (1969) records small numbers of *Euconchoecia* in the Atlantic and only in tropical and sub-tropical waters. Baker et al. (1977) recorded four specimens from Cedar Bayou off Texas, but from his illustrations his exact identification is uncertain. Angel (1979) reported *E. chierchiae* to be absent from the the northeast Atlantic at 30° N, 23° W, and a density of 0.6 m^3 in the night sample at 0–10 m at 32°N, 65°W. The true geographical range remains to be determined given the confusion apparent in the earlier identifications of this species. There has also been much confusion over the identification of *E. aculeata*, so its geographical range is also difficult to determine. *Euconchoecia omanensis* and *E. hormuzensis* were both found in large numbers in the Gulf of Oman, and may have become specifically adapted to the changing conditions of upwelling events caused by the seasonal monsoons.

Key to the species of *Euconchoecia* in this paper

Female

1. Posterior dorsal corner, left tip to posterior hinge ca. 6% CL 2

   Posterior dorsal corner, left tip to posterior hinge ca. 12% CL 3

2. CL ca. 1.3 mm; carapace height ca. 44% CL; frontal organ marginally shorter than first antenna .... *E. chierchiae*

   CL ca. 1.3 mm; carapace height ca. 50% CL; frontal organ marginally longer than first antenna .... *E. aculeata*

3. CL ca. 1.0 mm; carapace height ca. 42% CL; frontal organ marginally longer than first antenna .... *E. hormuzensis*

   CL ca. 1.4 mm; carapace height ca. 33% CL; frontal organ significantly longer than first antenna .... *E. omanensis*

Male

1. Carapace height ca. 55% CL; frontal organ shorter than first antenna 2

   Carapace height ca. 40% CL; frontal organ longer than first antenna 3

2. CL ca. 1.3 mm; right clasper shank length ca. 9% CL . . . . *E. chierchiae*

   CL ca. 1.0 mm; right clasper shank length ca. 2% CL . . . . *E. aculeata*

3. CL ca. 1.0 mm; frontal organ marginally longer than first antenna . . . . *E. hormuzensis*

   CL ca. 1.2 mm; frontal organ significantly longer than first antenna . . . . *E. omanensis*

Acknowledgements

I am very grateful to Dr Martin Angel of the Southampton Oceanography Centre for all his help and support and Professor Geoff Boxshall and the staff at the Natural History Museum, London for providing the material. I especially thank my husband Raymond Graves for his help with the tables, his constructive criticism of the paper and his continual support.

References

Angel MV. 1979. Studies on Atlantic halocyprid ostracods: their vertical distributions and community structure in the central gyre region along latitude 30°N from off Africa to Bermuda. Prog Oceanogr. 8:1–122.

Angel MV. 1999. Ostracoda. In: Boltovskoy D, editor. South Atlantic Zooplankton, Backhuys Publishers, Leiden: The Netherlands. p. 815–868.

Angel MV, Blachowiak-Samolyk K. 2006. *Obtusoecia* (Halocyprida: Myodocopa: Ostracoda) a bipolar planktonic oceanic genus: taxonomy, bathymetry and zoogeographical distribution. Ann Zool (Wars). 56(1):1–48.

Baker JH, Jones TL, Salinas J. 1977. Occurrence of *Euconchoecia chierchiae*, Muller,1890, (Ostracoda, Halocyprididae) in Cedar Bayou, Chambers County, Texas. Chesapeake Sci. 18(4):394

Boxshall GA. 1998. Comparative limb morphology in major crustacean groups: the coxal-basis joint in post-mandibular limbs. In: Fortey RA, Thomas RH, editors. Arthropod Relationships, Systematics Association special volume, Series 55, London: Chapman and Hall. p. 155–167.

Brady GS. 1902. On new or imperfectly known Ostracoda, chiefly from a collection in the Zoological Museum, Copenhagen. Trans Zool Soc London. 16:179–210.

Chavtur VG. 1976. Fauna of pelagic ostracods of the far-eastern seas of the USSR. In: Coastal biocenoses of the Far Eastern Seas of the USSR, Nauk, Vladivostok, 99–109.

Chen R, Lin J. 1984. A new species of *Euconchoecia* from the East China Sea. Acta Oceanol Sin. 5 suppl.: 859–861.

Cleve PT. 1900. The seasonal distribution of Atlantic plankton organisms, Göteborg, 1900, 38–40.

Cleve PT. 1905. The plankton of the South African Seas. III Halocyprididae. Marine Investigations in South Africa, 4, 129–132.

Da Rocha CEF. 1983. Distribution of *Euconchoecia* G.W.Müller (Crustacea, Ostracoda) off Santos Brazil. Bol Zool. 6:53–61.

Deevey GB. 1968. Pelagic ostracods of the Sargasso Sea off Bermuda. Bull Peabody Mus Nat Hist 26: 1–125.

George J. 1977. Studies on planktonic ostracods of the Northern Indian Ocean. PhD. Thesis, University of Cochin.

Herring PJ, Howell PR, Roe HSJ. 1998. Scheherazade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb – 30 Apr 1997. No11. Biomass data. Leg 1, 12 Feb – 19 Mar 1997 and Southampton Oceanography Centre Research and Consultancy Report No. 25, 4pp and figs/tables/appendix. (Unpunlished manuscript).

Herring PJ, Howell PR, Pugh PR. 1999. Scheherazade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb – 30 Apr 1997. No 16, Fish, decapod shrimps and siphonophores: abundances and size data. Leg1. 12 Feb – Mar 1997 and Southampton Oceanography Centre Research and Consultancy Report No. 25, 4pp and figs/tables/appendix. (Unpunlished manuscript).

Kornicker LS. 2003. Morphology and musculature of the fifth and sixth limbs of Halocyprida (Ostracoda-Myodocopa). J Crustacean Biol. 23: 765–776.

Müller GW. 1890. Ueber Halocypriden. Zool Jahrb. 5:211–252.

Müller GW. 1906. Ostracoda. Wissens Ergeb Deutsch Tiefsee-Exp '*Valdivia*' 1989–1899. 8: 29–154.

Müller GW. 1912. Ostracoden. Das Tierreich, 31:1–434.

Poulsen EM. 1969. Ostracoda-Myodocopa. 3a Halocypriformes-Thaumatocypridae and Halocypridae. Dana Rep. 75:1–100.

Roe HSJ, Shale DM. 1979. A new multiple rectangular midwater trawl (RMT1+8) and some modifications to the Institute of Oceanographic Sciences' RMT1+8. Mar Biol 50, 283–288.

Roe HSJ, Baker AdeC, Carson RM, Wild RA, Shale DM. 1980. Behaviour of the Institute of Oceanographic Sciences' rectangular midwater trawls; theoretical aspects and experimental observations. Marine Biol. 56:247–259.

Scott T. 1894. Report on Entomostraca from the Gulf of Guinea collected by John Rattray BSc. Trans Linn Soc London Series 2. 6:1–16.

Skogsberg T. 1920. Studies on marine ostracods. Part 1. (Cypridinids, halocyprids and polycopids). Zool Bidr Uppsala Suppl. 1:1–784.

Tseng WY. 1969. *Euconchoecia* (Ostracoda) from Taiwan Straits. Rep Taiwan Lab Fish Biol. 19:1–26.

Tseng WY. 1975. Biology of the pelagic ostracod, *Euconchoecia elongata* Müller. Rep Taiwan Lab Fish Biol. 27:1–183.

Vavra V. 1906. Die Ostracoden (Halocypriden und Cypridiniden) der Plankton-Expedition. Ergebn Plankton-Exp Humboldt-Stiftung. 2:1–76.

Journal of Natural History
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tnah20

Mamilloecia indica (Halocyprididae: Ostracoda) a new genus and species from the Northwest Indian Ocean

Carol Graves [a]
[a] Zoology Department, Natural History Museum, Cromwell Road, London, SW7 5BD, UK

Available online: 03 Feb 2012

To cite this article: Carol Graves (2012): Mamilloecia indica (Halocyprididae: Ostracoda) a new genus and species from the Northwest Indian Ocean, Journal of Natural History, 46:9-10, 517-556

To link to this article: http://dx.doi.org/10.1080/00222933.2011.649017

Journal of Natural History
Vol. 46, Nos. 9–10, March 2012, 517–556

Mamilloecia indica (Halocyprididae: Ostracoda) a new genus and species from the Northwest Indian Ocean

Carol Graves*

Zoology Department, Natural History Museum, Cromwell Road, London, SW7 5BD, UK

(*Received 5 July 2011; final version received 8 December 2011; printed 26 January 2012*)

A stratified zooplankton sample series taken from the upwelling region of the Gulf of Oman during February 1997 was analysed. Samples collected from below 1500 m contained an abundant species that closely resembled *Paraconchoecia mamillata* Müller, 1906 found in the Atlantic. Morphological and statistical analysis showed that the Oman species differed significantly from *P. mamillata*. In addition, both species differed significantly from *Paraconchoecia spinifera*, the type species of the genus *Paraconchoecia*. A new genus is erected to accommodate both the Oman and Atlantic species, together with the closely related *Paraconchoecia nanomamillata* Deevey and Brooks, 1980. Comprehensive redescriptions of *P. spinifera* and *Mamilloecia mamillata* new combination are given along with full descriptions of the new genus and species *Mamilloecia indica*.

Keywords: *Paraconchoecia*; ostracods; Myodocopida; plankton; Indian Ocean; Atlantic Ocean; taxonomy

Introduction

In the spring of 1997, during the Northeast monsoon, the RRS *Charles Darwin* undertook the "Scheherezade" cruise to investigate the influence of upwelling on biological processes in the Gulf of Oman. During the cruise a series of horizontal tows was made with the multiple rectangular midwater trawl (RMT1+8) net system (Roe and Shale 1979, Roe et al. 1980) at an oceanic station (*Discovery* 54001, 24°12′ N, 58°40′ E). The water column was sampled in 50-m, 100-m and 200-m depth zones to a depth of 2000 m.

Planktonic ostracods were sorted from the RMT1 samples and analysed for bathymetric distribution and species composition. Ostracods are typically small (0.5–3 mm) and extremely abundant in marine mesozooplankton communities. They occur in all oceans and at all depths throughout the water column. They feed on the detrital flux sinking from the surface into the deep ocean and hence play an important ecological role in the food webs and carbon fluxes (Angel et al. 2007).

In deep water samples (below 1500 m) in the Gulf of Oman there was an abundant population (379 females and 186 males) of a species that is superficially very similar to *Paraconchoecia mamillata* (Müller 1906) recorded in the Atlantic. Detailed morphometric examination and statistical analysis of specimens from the Gulf and the Atlantic was undertaken to determine if the two forms were conspecific. It was

*Email: c.graves@nhm.ac.uk

ISSN 0022-2933 print/ISSN 1464-5262 online

http://dx.doi.org/10.1080/00222933.2011.649017
http://www.tandfonline.com

also noted that both of these forms showed striking external differences from the type species of *Paraconchoecia*, *Paraconchoecia spinifera* Claus, 1891. Consequently, the comparisons were extended to include *P. spinifera* to ascertain whether or not they could be considered congeneric. As a result of this study, a new genus is erected to accommodate the species complex related to *P. mamillata*, with the new species from the Gulf of Oman being designated as the type species. In this paper a detailed redescription of *P. spinifera* is given, followed by detailed descriptions of both the species in *Mamilloecia.*

Materials and methods

The Atlantic material described in this report was derived from the following:

(1) The RRS *Discovery* cruise of 1972, *Discovery* Station 7856 (30° N, 23° W). The net used was the multiple rectangular midwater trawl (RMT1+8) net system (Roe and Shale 1979, Roe et al. 1980). The ostracod species *P. spinifera* was sorted from the RMT1 600–500-m depth horizon sample. Station 7856 was considered to be reasonably close to the two locations from which the species was originally described by Claus (1891).
(2) The *P. mamillata* material was collected during the RRS *Discovery* cruise of 1976, *Discovery* Station 9022 (30°12′ N, 11°41′ W). The net used was the multiple rectangular midwater trawl (RMT1+8) net system (Roe and Shale 1979, Roe et al. 1980). The ostracods were sorted from the RMT1 2200–2000 m depth horizon sample and separated into species.

The material from both Station 7856 and Station 9022 was initially fixed on board ship in buffered 5% formalin and subsequently stored in 80% industrial methylated ethanol in the collections of the Natural History Museum, London.

The Gulf of Oman zooplankton samples were collected in 1997, during the Northeast monsoon (Herring et al. 1998, 1999), at Station 54001 from the 1600–1400 m depth horizon sample. Total zooplankton samples were initially fixed in 5% seawater formalin and transferred after 24 h into Steadman's preserving fluid (0.5% propylene phenoxetol, 4.5% propylene glycol, 5% formalin seawater solution) before being stored for later analysis at the Natural History Museum, London. In 2006 the Steadman's preserving fluid was replaced with 80% industrial methylated ethanol and the planktonic ostracods were picked out and sorted to species.

Measurements of carapace length, breadth and height were taken for both sexes of *P. spinifera*, both sexes of *Mamilloecia indica* and both sexes of *Mamilloecia mamillata*. A pilot study using scanning electron microscopy was undertaken on a specimen of *M. indica* to ascertain its potential for halocyprid taxonomy. The material for scanning was cleaned by hydrating in alcohol and cleaning in glycerol for 12 h, specimens were then dehydrated through graded ethanol before being placed in a critical-point dryer. The dried specimens were sputter coated with gold before being observed in a Phillips X50 microscope at 15 kV.

A statistical analysis of morphometric characters of the carapace was undertaken to compare *M. indica* sp. nov. with typical specimens of *M. mamillata* comb. nov. from the Atlantic. The computer software package SPSS was used for principal component analysis. Principal component analysis was chosen to show differences between individuals rather than groups. Measurements were taken from 20 specimens of each sex of the Oman species and 20 specimens of each sex of the Atlantic species. These measurements were obtained under a stereo-microscope and consisted of five external features of the carapace shape: height and lengths from rostrum to posterior dorsal corner, rostrum to tubercle, posterior dorsal corner to dorsal edge of tubercle and posterior dorsal corner to ventral edge of tubercle (Tables 1–4).

A female and a male of *P. spinifera*, the type species of the genus *Paraconchoecia*, were dissected. One female and one male of *M. indica* from the Oman samples and one female and one male of *M. mamillata* from the Atlantic samples were dissected. Before dissection, each specimen was placed on a cavity slide in lactophenol containing lignin pink, dissected and examined under a stereo-microscope. The limbs were mounted as temporary preparations in lactophenol and examined under an Olympus BH2 compound microscope using differential interference contrast. A standard set of measurements of the limbs and setae (Angel and Blachowiak-Samolyk 2006), and morphological characteristics was recorded. Using a drawing tube, pencil drawings were made of the complete animal and the individual dissected parts. These sketches were scanned, re-drawn using ADOBE ILLUSTRATOR and collated in ADOBE PHOTOSHOP. Skogsberg's (1920) nomenclature for the structure and setation from the antennae, mandible, maxilla, fifth limb, sixth limb and caudal furca has been used throughout.

Results

The scanning electron microscope study demonstrated the presence of sculpturing on the carapace surface, but the specimen was rather distorted and had collapsed (Figure 1). Halocyprids are planktonic and have light, uncalcified carapaces and this result was not entirely unexpected. This explains why there are currently no scanning electron micrographs of halocyprids in the literature.

Systematics

Class **OSTRACODA** Latreille, 1802
Subclass **MYODOCOPA** Sars, 1866
Order **HALOCYPRIDA** Dana, 1853
Suborder **HALOCYPRIDINA** Dana, 1853
Family **HALOCYPRIDIDAE** Dana, 1853
Subfamily **CONCHOECIINIAE** Claus, 1891
Genus ***Paraconchoecia*** Claus, 1891

Diagnosis

Carapace varies in size, shape and form. Right asymmetric gland opens near posterior ventral corner. Left asymmetric gland opens at dorso-posterior corner. There are no lateral glands. Dorso-posterior glands present in male. Frontal organ sexually dimorphic. First antenna spines absent and in male e-seta not widened distally. Masticatory pad of mandible endite forms single triangular plate.

Table 1. Female *Mamilloecia* measurements for principal component analysis (mm).

Species number	Rostrum to posterior dorsal corner	Height	Rostrum to tubercle	Posterior dorsal corner to above tubercle	Posterior dorsal corner to below tubercle
Atlantic					
1	1.76	0.66	1.74	0.20	0.32
2	1.66	0.64	1.70	0.22	0.30
3	1.68	0.60	1.70	0.22	0.30
4	1.76	0.64	1.74	0.20	0.32
5	1.68	0.64	1.70	0.24	0.30
6	1.78	0.66	1.78	0.24	0.32
7	1.74	0.68	1.78	0.28	0.34
8	1.70	0.64	1.72	0.22	0.30
9	1.74	0.64	1.76	0.22	0.32
10	1.76	0.66	1.76	0.18	0.30
11	1.72	0.64	1.74	0.18	0.34
12	1.70	0.60	1.74	0.18	0.30
13	1.70	0.64	1.74	0.22	0.32
14	1.76	0.64	1.78	0.18	0.26
15	1.72	0.66	1.74	0.20	0.30
16	1.74	0.62	1.76	0.22	0.30
17	1.64	0.58	1.68	0.20	0.30
18	1.68	0.62	1.68	0.18	0.32
19	1.78	0.68	1.78	0.18	0.30
20	1.70	0.66	1.70	0.24	0.34
Oman					
1	1.86	0.64	1.94	0.14	0.26
2	1.84	0.70	1.80	0.18	0.30
3	1.82	0.72	1.88	0.16	0.26
4	1.88	0.66	1.88	0.22	0.34
5	1.86	0.62	1.88	0.18	0.32
6	1.80	0.68	1.82	0.24	0.30
7	1.86	0.66	1.88	0.18	0.34
8	1.84	0.66	1.86	0.16	0.32
9	1.88	0.66	1.90	0.20	0.30
10	1.86	0.66	1.88	0.14	0.28
11	1.86	0.68	1.90	0.22	0.34
12	1.84	0.64	1.88	0.16	0.28
13	1.88	0.64	1.92	0.12	0.24
14	1.92	0.64	1.96	0.20	0.34
15	1.82	0.62	1.84	0.20	0.30
16	1.84	0.66	1.86	0.18	0.28
17	1.82	0.60	1.88	0.18	0.30
18	1.80	0.60	1.84	0.18	0.34
19	1.80	0.66	1.82	0.16	0.34
20	1.74	0.64	1.78	0.18	0.30

Table 2. Male *Mamilloecia* measurements for principal component analysis (mm).

Species number	Rostrum to posterior dorsal corner	Height	Rostrum to tubercle	Posterior dorsal corner to above tubercle	Posterior dorsal corner to below tubercle
Atlantic					
1	1.60	0.60	1.62	0.18	0.28
2	1.56	0.56	1.60	0.18	0.26
3	1.64	0.56	1.64	0.18	0.26
4	1.58	0.54	1.60	0.16	0.28
5	1.60	0.64	1.64	0.16	0.26
6	1.64	0.56	1.62	0.18	0.30
7	1.62	0.64	1.66	0.14	0.28
8	1.58	0.66	1.58	0.16	0.26
9	1.58	0.56	1.60	0.16	0.26
10	1.56	0.56	1.58	0.16	0.24
11	1.58	0.54	1.62	0.18	0.28
12	1.66	0.54	1.68	0.14	0.26
13	1.58	0.60	1.62	0.14	0.28
14	1.60	0.54	1.62	0.16	0.30
15	1.60	0.60	1.64	0.20	0.30
16	1.66	0.58	1.68	0.18	0.28
17	1.64	0.64	1.68	0.18	0.26
18	1.64	0.56	1.66	0.16	0.26
19	1.58	0.56	1.62	0.14	0.24
20	1.64	0.58	1.68	0.18	0.28
Oman					
1	1.60	0.60	1.62	0.18	0.28
2	1.56	0.56	1.60	0.18	0.26
3	1.64	0.56	1.64	0.18	0.26
4	1.58	0.54	1.60	0.16	0.28
5	1.60	0.64	1.64	0.16	0.26
6	1.64	0.56	1.62	0.18	0.30
7	1.62	0.64	1.66	0.14	0.28
8	1.58	0.66	1.58	0.16	0.26
9	1.58	0.56	1.60	0.16	0.26
10	1.56	0.56	1.58	0.16	0.24
11	1.58	0.54	1.62	0.18	0.28
12	1.66	0.54	1.68	0.14	0.26
13	1.58	0.60	1.62	0.14	0.28
14	1.60	0.54	1.62	0.16	0.30
15	1.60	0.60	1.64	0.20	0.30
16	1.66	0.58	1.68	0.18	0.28
17	1.64	0.64	1.68	0.18	0.26
18	1.64	0.56	1.66	0.16	0.26
19	1.58	0.56	1.62	0.14	0.24
20	1.64	0.58	1.68	0.18	0.28

Table 3. Total variance of females and males.

Component	Initial eigenvalues		Cumulative %	Extraction sums of squared loadings		
	Total	% of variance		Total	% of variance	Cumulative %
Female						
1	2.479	49.577	49.577	2.479	49.577	49.577
2	1.296	25.912	75.489	1.296	25.912	75.489
3	0.83	16.595	92.085			
4	0.363	7.26	99.345			
5	0.033	0.655	100.000			
Male						
1	3.090	61.790	61.79	3.090	61.790	61.790
2	0.948	18.960	80.75	0.948	18.960	80.750
3	0.653	13.062	93.812			
4	0.251	5.027	98.839			
5	0.058	1.161	100.000			

Notes: Components: 1, rostrum to posterior dorsal corner; 2, height; 3, rostrum to tubercle; 4, posterior dorsal corner to above tubercle; 5, posterior dorsal corner to below tubercle.

Table 4. Component matrix of females and males.

	Component	
	1	2
Females		
Rostrum to posterior dorsal corner	0.920	0.299
Height	0.369	0.586
Rostrum to tubercle	0.926	0.193
Posterior dorsal corner to above tubercle	−0.694	0.557
Posterior dorsal corner to below tubercle	−0.396	0.718
Males		
Rostrum to posterior dorsal corner	0.927	−0.042
Height	0.297	0.945
Rostrum to tubercle	0.883	0.025
Posterior dorsal corner to above tubercle	0.866	−0.147
Posterior dorsal corner to below tubercle	0.783	−0.174

Paraconchoecia spinifera Claus, 1891
(Figures 2–6)

Paraconchoecia spinifera Claus, 1891: 1–81, Brady and Norman, 1896: 695, Müller, 1906: 56, pl. IX, 1–10, 13–14, Müller, 1906: 66, Müller, 1906: 3 (Siboga), Vavra, 1906: 40, pl. 2, 29–36, Granata and Caporiacco, 1949: 32, Iles, 1953: 270, Leveau, 1965: 177, pl. 5 c–e; 6 a–c, not Leveau, 1967: 67, Deevey, 1968: 30, fig. 8 a–e, fig. 9 a–f, Angel, 1981: 560, fig. 194, Angel, 1993: 208, fig. 78.

Paraconchoecia spinifera Claus, 1891: 64 pl. X, Poulsen, 1973: 12–16, fig. 1 a–i, Chen and Lin, 1995: 76–77, pl. 88, 1–7.

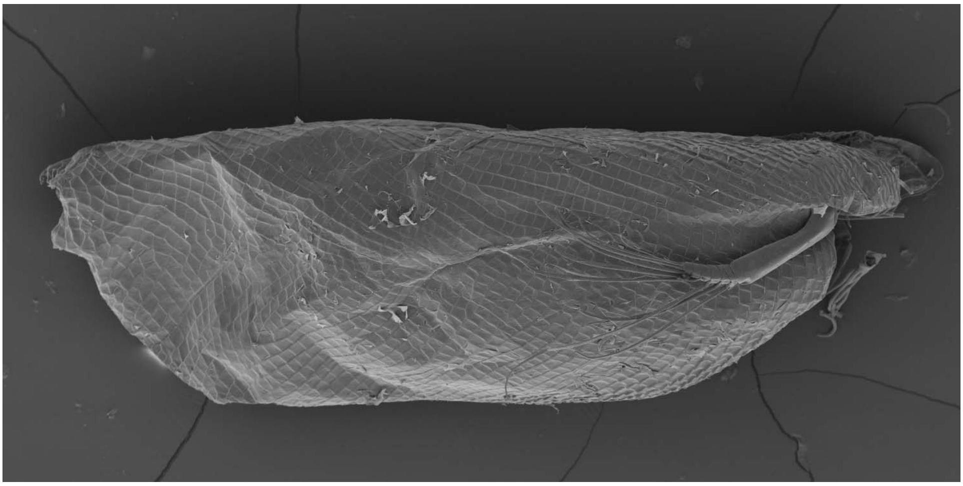


Figure 1. Scanning electron micrograph of female *Mamilloecia indica*.

Material

The material was collected from *Discovery* station 7856 (see above). Permanent preparations of dissected specimens used to prepare the illustrations in this paper have been deposited at the Natural History Museum, London: registration number NHMUK 2011.1613 for the female on slides and NHMUK 2011.1614 for the male on slides. The 100 males and 100 females that were measured are retained in 80% industrial methylated ethanol, registration numbers NHMUK 2011.1615–1624.

Description

The morphological characters of the carapaces and internal structures of both sexes, are listed in Tables 5–12, together with the comparative data for the other species examined: *M. indica* and *M. mamillata*.

Description of female

Carapace (Figure 2A–C). Mean length 1.77 $\pm$ 0.04 mm ($n = 100$). Carapace of exemplar specimen (Table 5) length 1.82 mm; height 0.90 mm; breadth 0.70 mm. Height : length ratio 49.5% carapace length (CL), breadth : length ratio 38.5%CL. Ventral margin of carapace with few striae running parallel to margin. Carapace slightly elongated with sharp edged shoulder vaults, maximum height anterior to mid-length. Ventral margin curving smoothly into posterior margin with asymmetric gland at ventral dorsal corner of right valve. Posterior dorsal corner of right valve furnished with two small spines. Posterior dorsal corner of left valve furnished with blunt process. On left valve asymmetric gland opening on dorsal margin anterior to end of hinge between valves.

Frontal organ (Table 5; Figure 2D). Frontal organ stem slender and almost straight, much longer than limb of first antenna. Capitulum bulbous with pointed tip. Distal end of dorsal surface with small spines. Ventral surface covered in small spines. Total length 39.6%CL longer than first antenna.

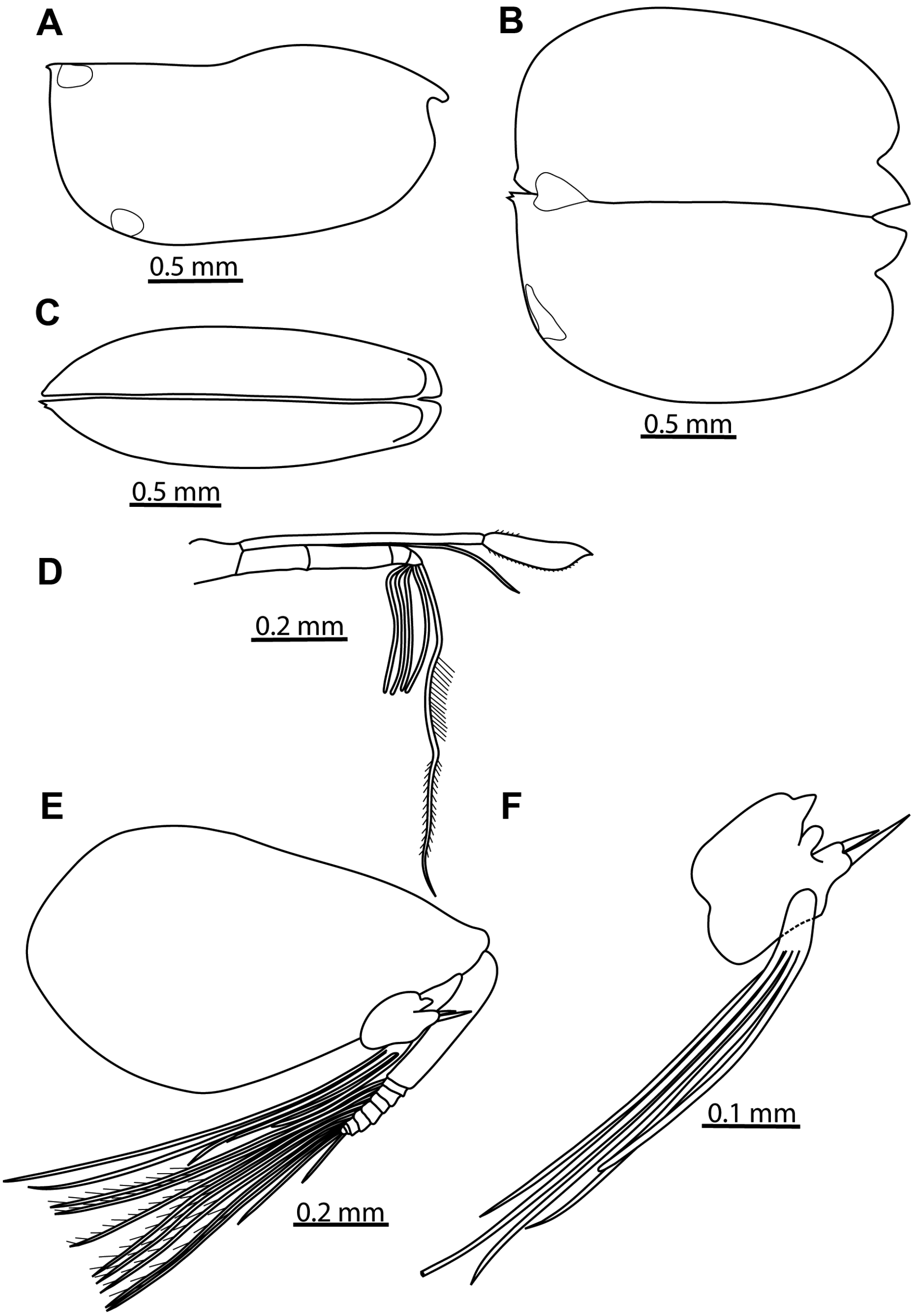


Figure 2. *Paraconchoecia spinifera* female: (A) Lateral view; (B) carapace dissected and viewed dorsally; (C) ventral view; (D) first antenna and frontal organ; (E) second antenna; (F) endopodite.

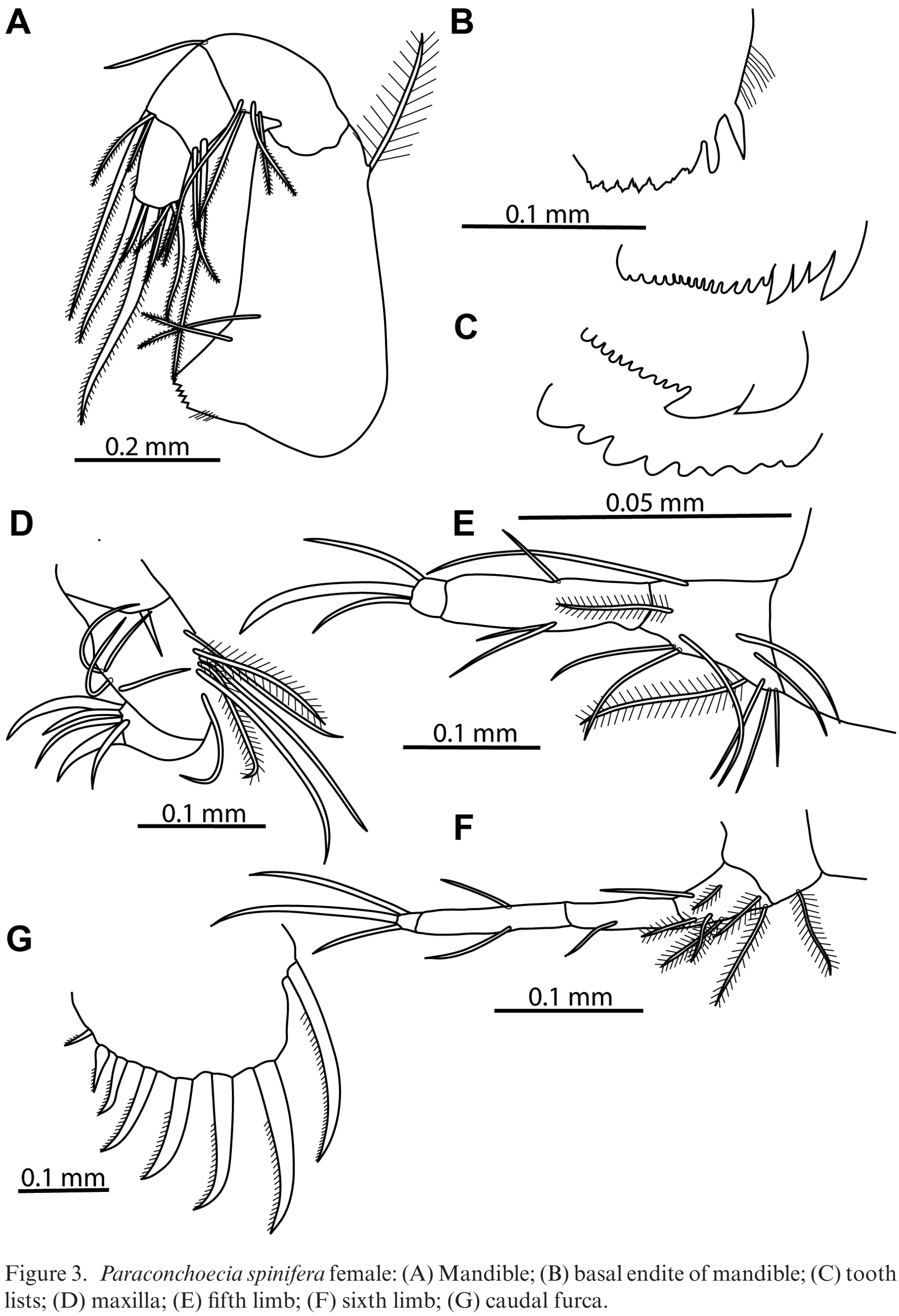


Figure 3. *Paraconchoecia spinifera* female: (A) Mandible; (B) basal endite of mandible; (C) tooth lists; (D) maxilla; (E) fifth limb; (F) sixth limb; (G) caudal furca.

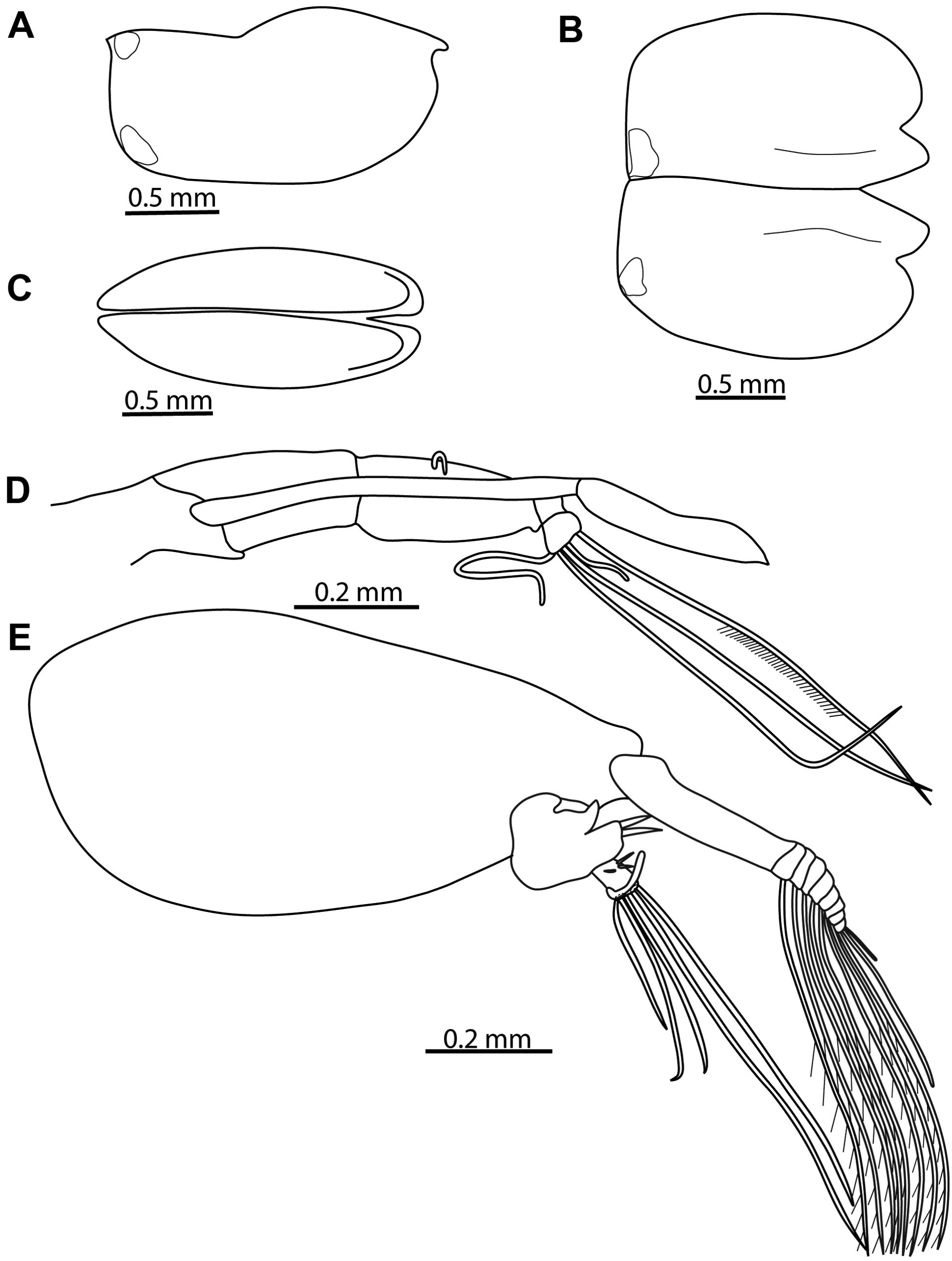


Figure 4. *Paraconchoecia spinifera* male: (A) Lateral view; (B) carapace dissected and viewed dorsally; (C) ventral view; (D) first antenna and frontal organ; (E) second antenna.

First antenna (Table 6; Figure 2D). Five-segmented. Limb length 30.0%CL. Third segment with dorsal seta 22.3%CL. Fifth segment with five unequal setae; a-seta 15.1%CL; b-seta 14.8%CL; c-seta 15.4%CL; d-seta 15.9%CL; e-seta 38.2%CL with long hairs on anterior face.

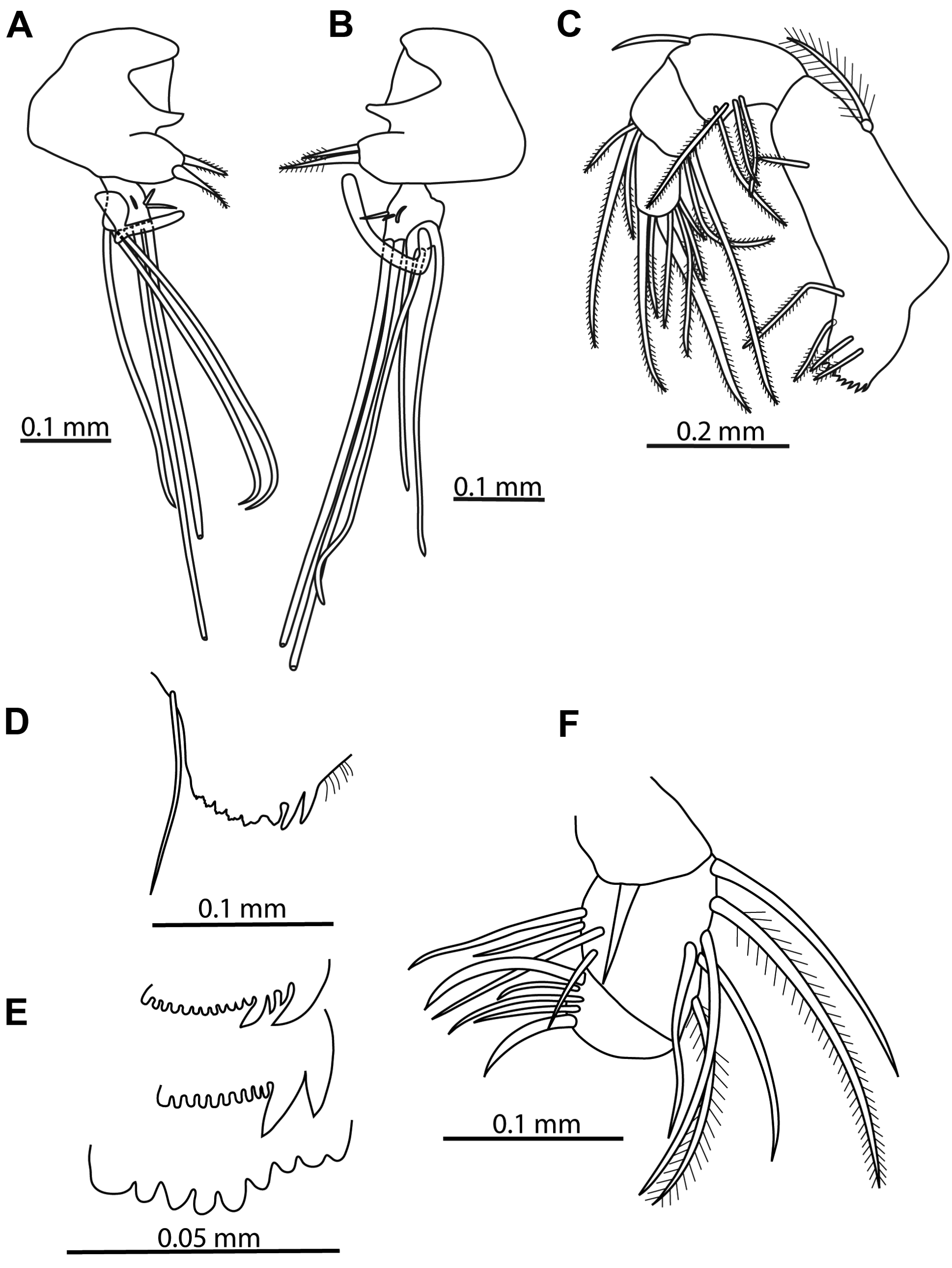


Figure 5. *Paraconchoecia spinifera* male: (A) Left endopodite of second antenna; (B) right endopodite of second antenna; (C) mandible; (D) basal endite of mandible; (E) tooth lists; (F) maxilla.

Second antenna (Table 6; Figure 2E). Protopodite 59.8%CL. First exopodite segment about one-third length of protopodite. All swimming setae much shorter than protopodite, all but shortest two setae with long hairs distally. Endopodite (Figure 2F)

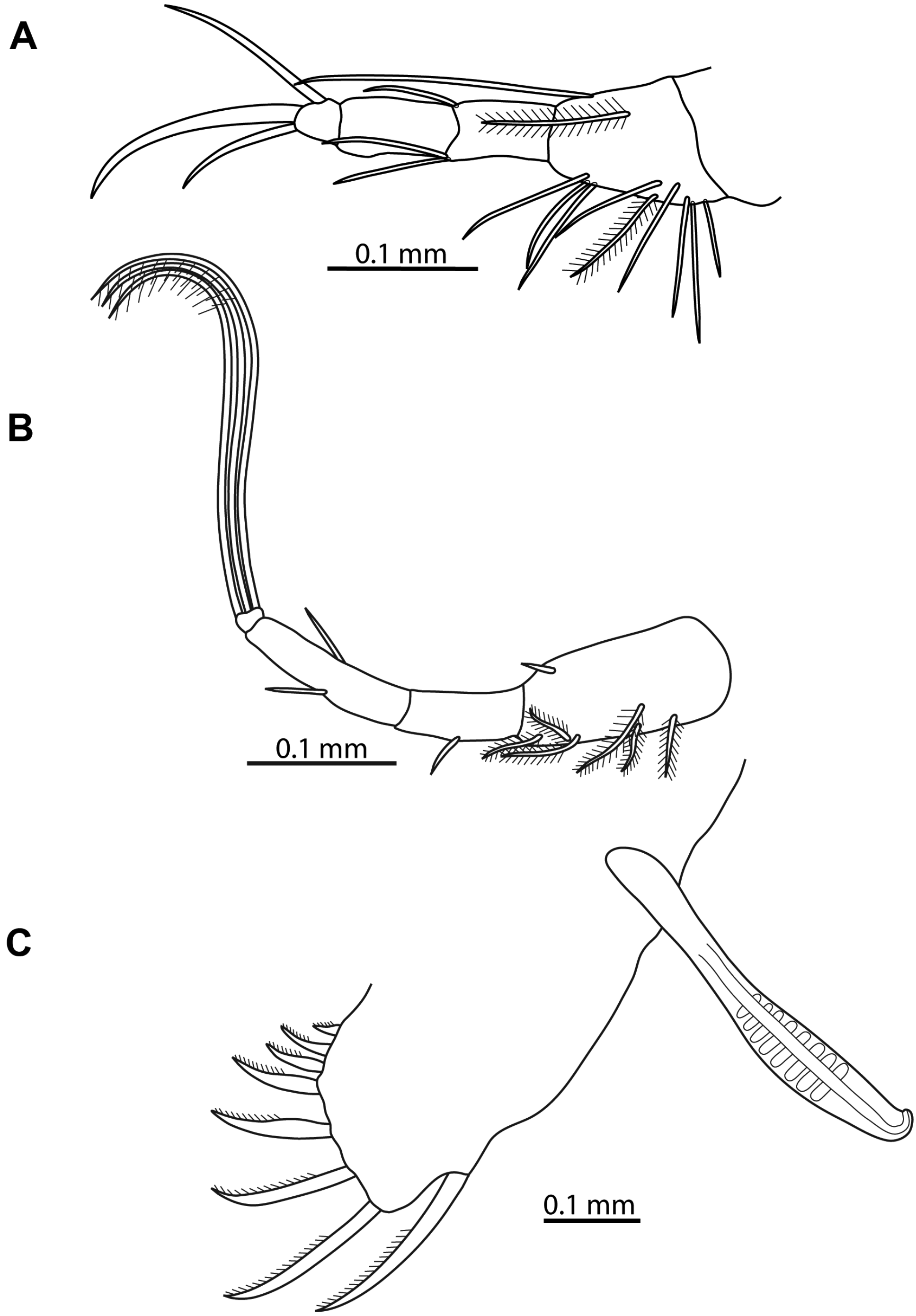


Figure 6. *Paraconchoecia spinifera* male: (A) Fifth limb; (B) sixth limb; (C) caudal furca.

Table 5. Female *Paraconchoecia* and *Mamilloecia* species comparisons.

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Carapace			
Length	1.82 mm	1.84 mm	1.74 mm
Height	0.90 mm	0.68 mm	0.68 mm
Breadth	0 70 mm	0.60 mm	0.56 mm
Height/length %	49.5%	37.0%	39.1%
Breadth/length %	38.5%	32.6%	32.2%
PDC, left tip to posterior hinge (%CL)	5.2%	5.7%	5.2%
PDC, right tip to posterior hinge (%CL)	6.0%	5.2%	4.3%
Rostrum, left tip to anterior hinge (%CL)	11.8%	11.7%	12.1%
Rostrum, right tip to anterior hinge (%CL)	11.8%	10.9%	11.8%
Incisure, left rostrum tip to inner edge (%CL)	13.7%	10.1%	12.4%
Incisure, right rostrum tip to inner edge (%CL)	13.2%	11.1%	11.5%
Opening of left gland	at PDC	at PDC	at PDC
Opening of right gland	close to PVC	at tubercle	at tubercle
Frontal organ			
Capitulum length (%CL)	12.4%	13.2%	13.5%
Stem length (%CL)	27.2%	24.3%	21.4%
Total length	39.6%	37.5%	34.9%
Stem length relative to antenna 1	longer	significantly longer	significantly longer

Notes: $n = 1$, %CL, % of carapace length; PDC, posterior dorsal corner; PVC, posterior ventral corner.

with short, pointed bare a- and b-setae; c-, d- and e-setae absent; f- and g-setae respectively 26.4%CL and 44.2%CL; h-seta 16.2%CL; i-seta 22.3%CL; j-seta 22.0%CL.

Mandible (Table 7) (Figure 3A–C). Coxale toothed edge of pars incisiva with nine large blunt teeth. Distal tooth list with two large and about 10 small pointed teeth. Proximal tooth list slightly narrower with four large teeth and about 15 small pointed teeth. Outer margin of toothed edge of basal endite with two large dagger-shaped teeth, tip of second rounded, one small pointed tooth and five subserrate teeth. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with one bare dorsal seta and four finely spinose ventral setae. Second segment with two ventral and three dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla (Table 7; Figure 3D). Basal segment with four naked and two plumose anterior setae, one lateral and four posterior setae. Distal segment comparatively short and wide with five bare terminal claw setae, posteriormost longest.

Fifth limb (Table 8; Figure 3E). Ventrally basale with five setae and one plumose seta, laterally one plumose and two bare setae, dorsally single long seta – remnant of

Table 6. Female *Paraconchoecia and Mamilloecia* species comparisons.

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Antenna 1			
Length segment 1 (%CL)	9.9%	7.1%	4.3%
Length segment 2 (%CL)	7.3%	7.1%	3.0%
Length segment 3 (%CL)	9.6%	6.0%	6.6%
Length segment 4 (%CL)	1.6%	1.5%	1.9%
Length segment 5 (%CL)	1.4%	1.2%	1.0%
Total length (%CL)	30.0%	22.8%	16.8%
a-seta (%CL)	15.1%	14.1%	16.7%
b-seta (%CL)	14.8%	14.7%	17.8%
c-seta (%CL)	15.4%	14.7%	17.2%
d-seta (%CL)	15.9%	15.8%	16.7%
e-seta (%CL)	38.2%	20.9%	26.1%
Dorsal seta (%CL)	22.3%	6.0%	5.8%
Antenna 2			
Protopodite (%CL)	59.8%	39.4%	32.3%
Exopodite 1 (%CL)	17.9%	16.0%	13.8%
Exopodite 2 - 9 (% exopodite 1)	46.2%	44.1%	54.2%
Longest swimming seta (%CL)	27.5%	29.9%	31.0%
Mid-length swimming seta (%CL)	15.7%	14.3%	21.0%
Shortest swimming seta (%CL)	6.0%	3.8%	7.9%
Endopodite segment 1 (%CL)	8.8%	7.3%	7.6%
a-seta (%CL)	2.3%	2.2%	2.6%
b-seta (%CL)	3.6%	4.3%	5.0%
Endopodite segment 2 (%CL)	2.9%	2.9%	2.9%
f-seta (%CL)	26.4%	16.8%	20.8%
g-seta (%CL)	44.2%	20.4%	23.9%
h-seta (%CL)	16.2%	11.7%	17.0%
i-seta (%CL)	22.3%	14.0%	19.7%
j-seta (%CL)	22.0%	12.1%	18.7%

Note: $n = 1$, %CL, % of carapace length.

exopodite. First segment with two ventral setae and one dorsal seta. Second segment with three unequal, curved terminal claw setae; middle claw longest, 6.9%CL.

Sixth limb (Table 8; Figure 3F). Basale with five plumose ventral setae, one plumose seta laterally and one dorsally. First endopodite segment with one ventral seta. Second segment with one seta ventrally and one dorsally. Third segment with three unequal, terminal claw setae; middle claw longest 14.0%CL.

Caudal furca (Table 8; Figure 3G). Eight pairs of claw setae diminishing in size dorsally; longest claw 11.8%CL.

Table 7. Female *Paraconchoecia and Mamilloecia* species comparisons.

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Mandible			
Basale			
Endopodite segment 1 dorsal setae	1 bare	1 long plumose	1 long plumose
Endopodite segment 1 ventral setae	4	4	4
Endopodite segment 2 dorsal setae	3	3	3
Endopodite segment 2 ventral setae	2	2	2
Endopodite segment 3 terminal setae	7	7	7
Endopodite segment 3 longest claw (%CL)	17.3%	15.2%	14.9%
Endopodite segment 3 longest claw (% limb)	64.9%	77.8%	76.5%
Teeth on basal endite	2 + 1 + 5	2 + 1 + 5	2 + 1 + 5
Pars incisiva	9	4 + 6	4 + 6
Distal tooth list	2 + 10	2 + 15	2 + 15
Proximal list	4 + 15	2 + 18	2 + 18
Setae laterally on endite	2 + 2	4	4
Exopodite	1 plumose	1 plumose	1 plumose
Maxilla			
Basal segment anterior setae	4 + 2 plumose	6	6
Basal segment lateral setae	1	1	1
Basal segment posterior setae	3	4	4
Terminal spines	0	0	0
Distal segment claw setae	2	2	2
Distal segment normal setae	3	3	3

Note: $n = 1$, %CL, % of carapace length.

Description of male

Carapace (Figure 4A–C). Mean length 1.77 ± 0.04 mm ($n = 100$). Carapace of exemplar specimen (Table 9) length 1.76 mm; height 0.86 mm; breadth 0.74 mm. Height: length ratio 48.9%CL, breadth : length ratio 42.0%CL. Ventral margin ornamented with few striae. Carapace slightly elongated with sharp-edged shoulder vaults; maximum height anterior to mid-length. Ventral margin curving smoothly into posterior margin with left asymmetric gland opening at posterior ventral corner. Posterior dorsal corner of right valve furnished with small spine and blunt process on left valve. Asymmetric gland of left valve opening onto posterior dorsal margin anterior to end of hinge between carapace valves.

Frontal organ (Table 9; Figure 4D). Frontal organ stem slender and almost straight, shorter than limb of first antenna. Capitulum, bulbous, bare with pointed tip. Total length 52.0%CL much longer than first antenna.

Table 8. Female *Paraconchoecia and Mamilloecia* species comparisons.

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Fifth limb			
Basale ventral setae	3 + 2 + 1 plumose	3 + 2 + 1 plumose	3 + 2 + 1 plumose
Basale lateral setae	2	2 + 1 plumose	2 + 1 plumose
Basale dorsal setae	1 long	1 long	1 long
Endopodite segment 1 ventral setae	2	2	2
Endopodite segment 1 dorsal setae	1	1	1
Height/length %	24.1%	26.1%	35.7%
Longest terminal seta (%CL)	6.9%	4.9%	5.6%
Longest seta/length segment 2	384.0%	400.0%	411.1%
Longest seta/length limb	43.1%	50.7%	41.6%
Sixth limb			
Basale ventral setae	2 + 2 + 1 all plumose	2 + 2 + 1 all plumose	2 + 2 + 1 all plumose
Basale lateral setae	1	1 plumose	1 plumose
Basale dorsal setae	1	1	1
Endopodite segment 1 ventral setae	1	1	1
Endopodite segment 1 dorsal setae	0	0	0
Endopodite segment 2 ventral setae	1	1	1
Endopodite segment 2 dorsal setae	1	1	1
Segment 2 height/length %			
Longest seta (%CL)	14.0%	11.0%	10.5%
Longest seta % segment 2	122.9%	168.8%	158.7%
Longest seta % limb	40.5%	48.2%	46.8%
Caudal furca			
Paired claws			
Longest claw (%CL)	11.8%	11.4%	9.3%

Note: $n = 1$, %CL, % of carapace length.

First antenna (Table 10; Figure 4D). Five-segmented. Limb length 49.7%CL. Third segment with small dorsal seta 3.4%CL. Fifth segment with five unequal setae; a-seta 21.0%CL; b-seta 6.8%CL; c-seta 42.3%CL; d-seta 38.9%CL; e-seta 53.4%CL with 30 pairs of spinules.

Second antenna (Table 10; Figure 4E). Protopodite 51.1%CL. First exopodite segment about one-third length of protopodite. All swimming setae much shorter than protopodite, all but shortest two setae bearing long hairs distally. Endopodite with

Table 9. Male *Paraconchoecia* and *Mamilloecia* species comparisons.

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Carapace			
Length	1.76 mm	1.56 mm	1.72 mm
Height	0.86 mm	0.60 mm	0.64 mm
Breadth	0.74 mm	0.64 mm	0.62 mm
Height/length %	48.9%	38.5%	37.2%
Breadth/length %	42.0%	41.0%	36.0%
PDC, left tip to posterior hinge (%CL)	3.1%	5.1%	4.9%
PDC, right tip to posterior hinge (%CL)	2.7%	4.2%	3.8%
Rostrum, left tip to anterior hinge (%CL)	23.9%	14.1%	12.5%
Rostrum, right tip to anterior hinge (%CL)	23.6%	13.5%	12.2%
Incisure, left rostrum tip to inner edge (%CL)	14.2%	15.1%	16.0%
Incisure, right rostrum tip to inner edge (%CL)	14.5%	13.8%	14.2%
Opening of left gland	at PDC	at PDC	at PDC
Opening of right gland	close to PVC	at tubercle	at tubercle
Frontal organ			
Capitulum length (%CL)	18.2%	18.9%	16.6%
Stem length (%CL)	33.8%	25.3%	26.7%
Total length (%CL)	52.0%	44.2%	43.3%
Stem length relative to antenna 1	shorter	shorter	shorter

Note: $n = 1$, %CL, % of carapace length; PDC, posterior dorsal corner; PVC, posterior ventral corner.

short, pointed, bare a-seta; b-seta pointed with hairs; c-, d- and e-setae present, but all very small; f- and g- setae respectively 38.4%CL and 44.7%CL; h-seta 19.6%CL; i-seta 24.1%CL; j-seta 20.5%CL. Right endopodite (Figure 5B) with elongated clasping organ in form of hook with long proximal shank and very long curved end piece 8.2%CL. Left endopodite (Figure 5A) ‘hook’ much shorter and straight 4.7%CL.

Mandible, maxilla and fifth limb (Table 11, 12; Figures 5C–F, 6A). Structure and arrangement of setae on mandible, maxilla and fifth limb as for female.

Sixth limb (Table 12; Figure 6B). Basale with five plumose setae ventrally, one laterally, and very short bare dorsal exopodal seta. First endopodite segment with one ventral seta. Second endopodite segment with single seta both ventrally and dorsally. Third segment with three terminal setae. Three subequal, very long setae 35.5%CL evenly curved ventrally with long hairs distally 35.5%CL.

Caudal furca (Table 12; Figure 6C). Structure and arrangement of furcal claws similar to female. Longest claw 12.2%CL.

Intromittent organ (Table 12; Figure 6C). Male copulatory appendage exceptionally long, 25.9%CL with eight oblique muscles.

Table 10. Male *Paraconchoecia* and *Mamilloecia* species comparisons.

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Antenna 1			
Length segment 1 (%CL)	18.2%	9.8%	7.3%
Length segment 2 (%CL)	10.5%	9.5%	7.7%
Length segment 3 (%CL)	15.9%	9.1%	13.8%
Length segment 4 (%CL)	2.6%	5.6%	5.4%
Length segment 5 (%CL)	2.6%	4.5%	2.9%
Total length (%CL)	49.7%	38.5%	37.1%
a-seta (%CL)	21.0%	19.9%	24.1%
b-seta (%CL)	42.3%	33.0%	38.4%
c-seta (%CL)	6.8%	9.9%	11.6%
d-seta (%CL)	38.9%	29.5%	38.4%
e-seta (%CL)	53.4%	42.3%	40.7%
e-seta armature	30 pairs of spines	double row of fine hairs	double row of fine hairs
Dorsal seta (%CL)	3.4%	4.6%	5.7%
Antenna 2			
Protopodite (%CL)	51.1%	46.5%	42.2%
Exopodite 1 (%CL)	18.2%	16.0%	16.9%
Exopodite 2 - 9 (% exopodite 1)	50.0%	56.0%	44.8%
longest swimming seta (%CL)	36.4%	38.5%	28.5%
Mid-length swimming seta (%CL)	16.8%	22.1%	9.0%
Shortest swimming seta (%CL)	2.7%	9.9%	2.5%
Endopodite segment 1 (%CL)	9.4%	6.1%	7.6%
a-seta (%CL)	3.0%	3.8%	3.6%
b-seta (%CL)	4.1%	5.4%	5.4%
Endopodite segment 2 (%CL)	4.0%	4.2%	3.2%
f-seta (%CL)	38.4%	35.9%	35.8%
g-seta (%CL)	44.7%	29.2%	33.7%
Right clasper shank length (%CL)	8.2%	10.1%	6.8%
Left clasper shank length (%CL)	4.7%	5.3%	4.3%
h-seta (%CL)	19.6%	7.7%	11.6%
i-seta (%CL)	24.1%	16.3%	12.9%
j-seta (%CL)	20.5%	13.8%	12.4%

Note: $n = 1$, %CL, % of carapace length.

Remarks

The genus *Paraconchoecia* was defined by Claus (1891) and *P. spinifera* was designated type species by Poulsen (1973) when he redefined the genus. *Paraconchoecia spinifera*

Table 11. Male *Paraconchoecia* and *Mamilloecia* species comparisons.

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Mandible			
Basale			
Endopodite segment 1 dorsal setae	1 bare	1 long plumose	1 plumose
Endopodite segment 1 ventral setae	4	4	4
Endopodite segment 2 dorsal setae	3	3	3
Endopodite segment 2 ventral setae	2	2	2
Endopodite segment 3 terminal setae	7	7	7
Endopodite segment 3 longest claw (%CL)	17.3%	16.3%	16.9%
Endopodite segment 3 longest claw (% limb)	62.2%	78.5%	85.3%
Teeth on basal endite	2 + 1 + 5	2 + 1 + 5	2 + 1 + 5
Pars incisiva	9	4 + 6	4 + 6
Distal tooth list	2 + 10	2 + 15	2 + 17
Proximal list	4 + 12	2 + 18	2 + 16
Setae laterally on endite	2 + 2	4	4
Exopodite	1 plumose	1 plumose	1 plumose
Maxilla			
Basal segment anterior setae	4 + 2 plumose	6	6
Basal segment lateral setae	1	1	1
Basal segment posterior setae	3	4	4
Terminal spines	0	0	0
Distal segment claw setae	2	2	2
Distal segment normal setae	3	3	3

Note: $n = 1$, %CL, % of carapace length.

has been redescribed by Brady and Norman (1896), Müller (1906, 1912), Skogsberg (1920), Deevey (1968) and Poulsen (1973), Müller (1912) recorded *P. spinifera* from the Atlantic, Indian and Pacific oceans and Granata and Caporiacco (1949) reported it in the Mediterranean. Skogsberg (1920) suggested that the diagnosis of the genus by Claus (1891) was insufficient because the only character defined by him was the masticatory pad of the basal endite of the mandible. Müller (1906) added the character of the long hairs or spines on the e-seta of the first antenna and the absence of lateral glands.

Mamilloecia Graves gen. nov.

Conchoecia (part) Müller, 1906a: 60, pls 16,1–9,35, 8, Müller 1906b: 6, Müller, 1912: 70, Granata and Caporiacco, 1949: 30, Iles, 1953: 269, Rudjakov, 1962: 175,fig. 1a–e,

Table 12. Male *Paraconchoecia* and *Mamilloecia* species comparisons.

	Paraconchoecia spinifera	*Mamilloecia indica*	*Mamilloecia mamillata*
Fifth limb			
Basale ventral setae	3 + 3 + 1 plumose	3 + 2 + 1 plumose	3 + 2 + 1 plumose
Basale lateral setae	2 + 1 plumose	2 + 1 plumose	2 + 1 plumose
Basale dorsal setae	1 long	1 long	1 long
Endopodite segment 1 ventral setae	2	2	2
Endopodite segment 1 dorsal setae	1	1	1
Height/length %	31.0%	32.5%	28.6%
Longest terminal seta (%CL)	8.4%	6.3%	5.7%
Longest seta/length segment 2	491.7%	520.0%	780.0%
Longest seta/limb length	50.0%	48.1%	49.4%
Sixth limb			
Basale ventral setae	2 + 2 + 1 all plumose	2 + 1 + 2 all plumose	2 + 2 + 1 all plumose
Basale lateral setae	1 plumose	1 plumose	1 plumose
Basale dorsal setae	1	1	1
Endopodite segment 1 ventral setae	1	1	1
Endopodite segment 1 dorsal setae	0	0	0
Endopodite segment 2 ventral setae	1	1	1
Endopodite segment 2 dorsal setae	1	1	1
Segment 2 height/length%	22.9%	30.0%	27.1%
Longest seta (%CL)	35.5%	22.1%	23.0%
Shortest seta (%CL)	all subequal	4.2%	3.8%
Longest seta % segment 2	260.4%	345.0%	329.2%
Longest seta % limb	96.9%	94.5%	103.9%
Caudal furca			
Longest claw (%CL)	12.2%	14.3%	14.2%
Intromittent organ			
Length (%CL)	25.9%	26.9%	29.7%

Note: $n = 1$, %CL, % of carapace length.

Deevey, 1968: 36, fig. 12 d – f, Deevey, 1974: 361, Deevey, 1978a: 51, Deevey and Brooks, 1980: 66 fig. 11eh, 12a, 13b,e–j, Angel, 1981: 559, fig. 19 4–6.

Paraconchoecia (part) Poulsen, 1973: 42–43, fig. 16a–j, Chavtur, 1977: 144, 1993 Angel, 1993:186 fig. 67, Chen and Lin 1995: 72 fig. 831–3, Angel, Blachowiak-Samolyk, Drapun and Castillo, 2007: 11 fig. 8.

Etymology

The name is derived from the original specific name of *mamillata* and *–oecia* the standard ending for the majority of genera of the subfamily Conchoecinae.

Type species: *Mamilloecia indica* Graves, by original designation.

Diagnosis

Carapace faintly sculptured with parallel lines running at approximately 45° to ventral surface. Right carapace valve with small tubercle at mid-height along posterior margin. Left valve has similar tubercle just below posterior dorsal corner. Asymmetrical carapace glands open at apices of tubercles. Frontal organ sexually dimorphic: female long stem, straight and slender capitulum; male short stem with broad down-turned capitulum clearly sutured with stem. Armature of male first antenna e-seta bears dense line of fine hairs and widens distally. Second antenna endopodite f- and g-setae widened distally. In both sexes, mandible dorsal seta of first segment long and plumose; longest claw more than three-quarters carapace length. Maxilla basal segment bears six bare anterior setae with four posterior setae, distal segment bears two claw setae and three normal setae. Terminal segment of sixth limb of male bears two long subequal setae with fine hairs distally and one short bare terminal setae.

Mamilloecia indica sp. nov.
(Figures 7–11)

Type material

Permanent preparations of the dissected holotype and allotype are deposited in the collections of the Natural History Museum, London registration number NHMUK 2011.1625 for the holotype (female) on slides and NHMUK 2011.1626 for the allotype (male) on slides. The remaining 100 female and 100 male paratypes are retained in 80% industrial methylated ethanol registration numbers NHMUK 2011.1627–1636 for.

Etymology

The specific name refers to the type locality of the Indian Ocean.

Description

The morphological characters of the carapaces and internal structures are listed in Tables 5–12 together with comparative data for the other species described here.

Description of female

Carapace (Figure 7A–C). Mean length 1.88 ± 0.04 mm ($n = 100$). Carapace of exemplar specimen (Table 5) length 1.84 mm; height 0.68 m; breadth 0.60 mm. Height: length ratio 37.0%CL, breadth : length ratio 32.6%CL. In lateral view carapace

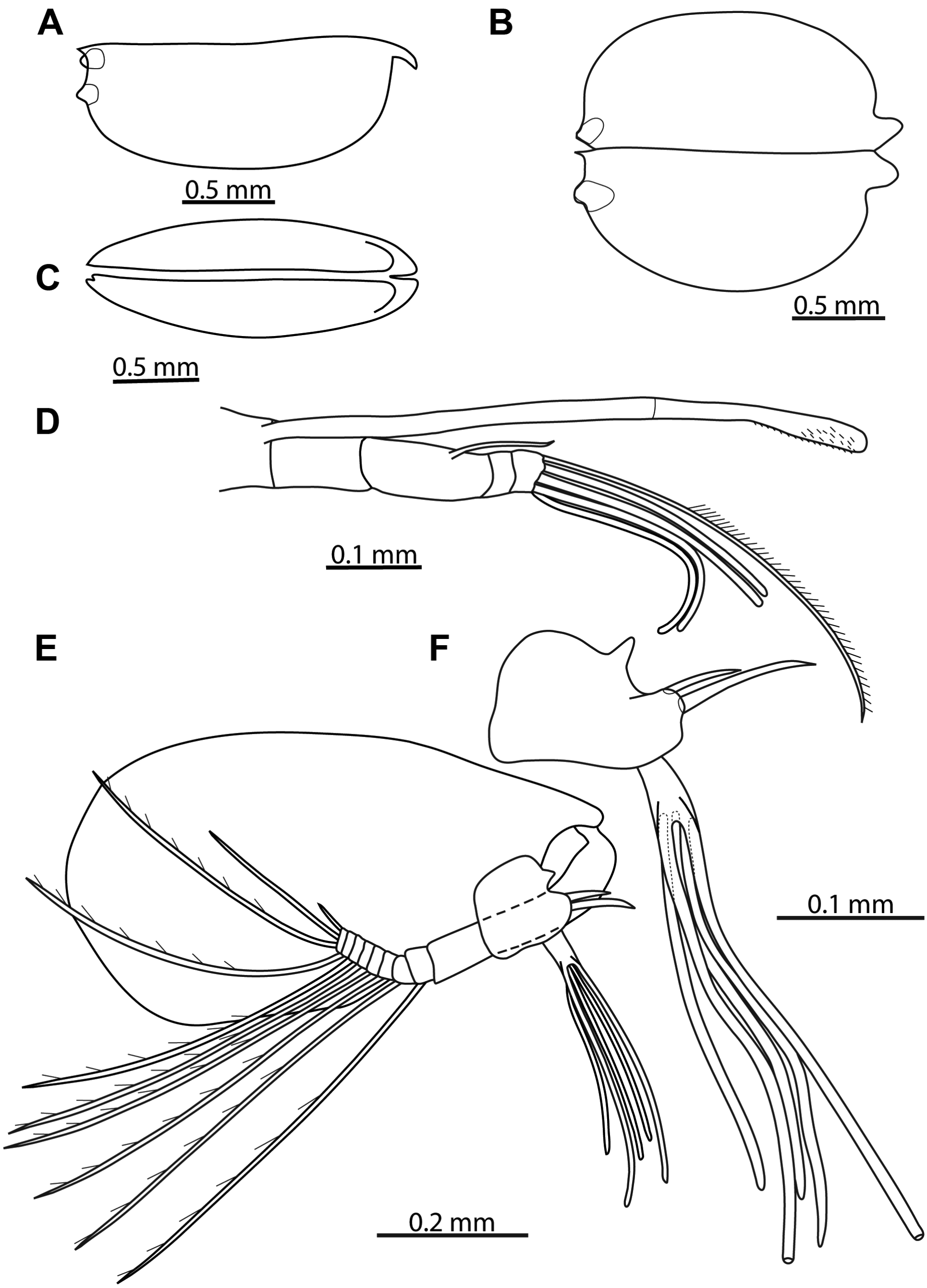


Figure 7. *Mamilloecia indica* female gen. nov., sp. nov.: (A) Lateral view; (B) carapace dissected and viewed dorsally; (C) ventral view; (D) first antenna and frontal organ; (E) second antenna; (F) endopodite.

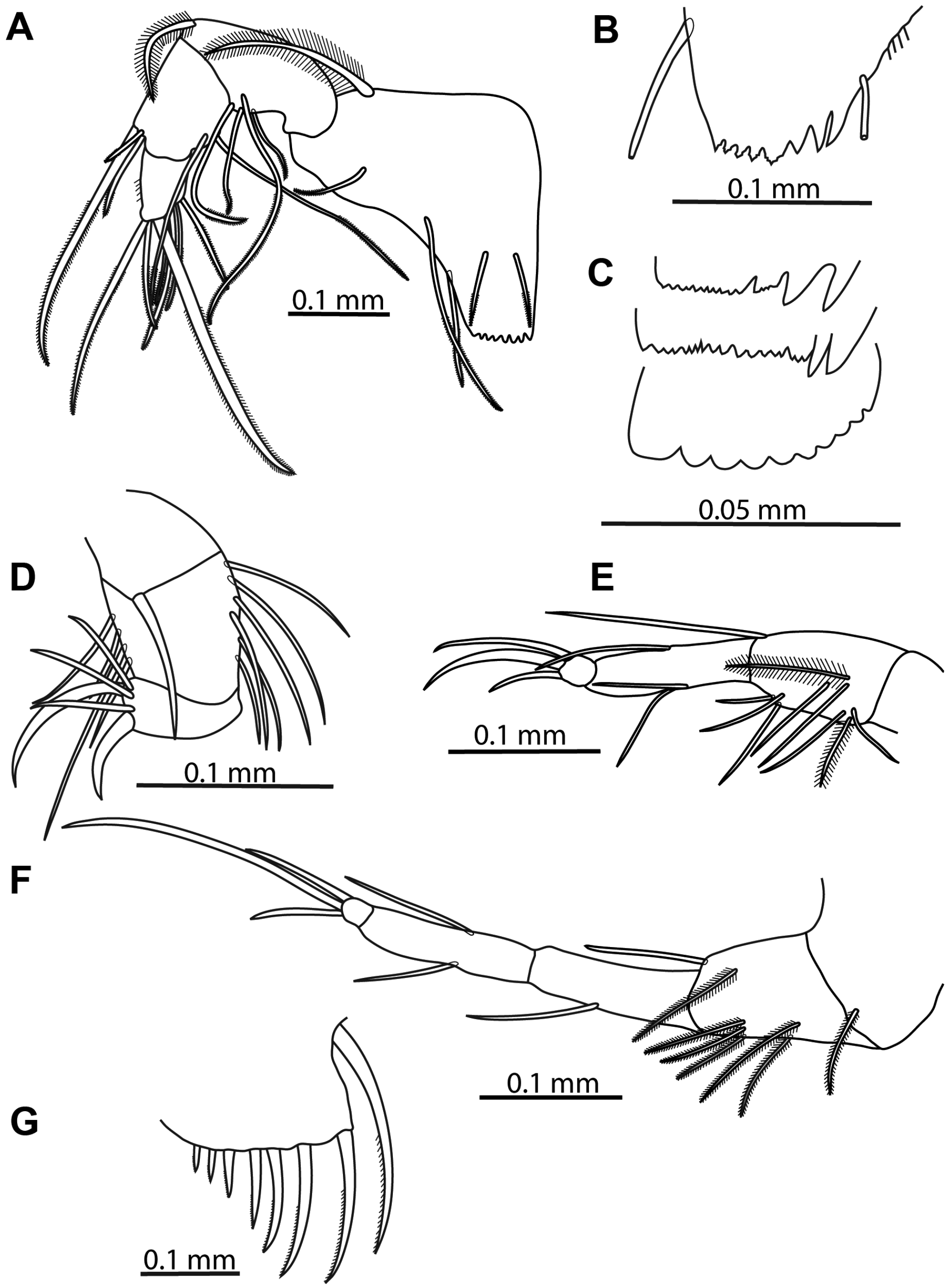


Figure 8. Mamilloecia *indica* female gen. nov., sp. nov.: (A) Mandible; (B) basal endite of mandible; (C) tooth lists; (D) maxilla; (E) fifth limb; (F) sixth limb; (G) caudal furca.

faintly sculptured with parallel lines running at approximately 45° to ventral surface. Carapace slightly elongated, maximum height just anterior to mid-length. Ventral margin curving smoothly into posterior margin. At mid-height on posterior margin

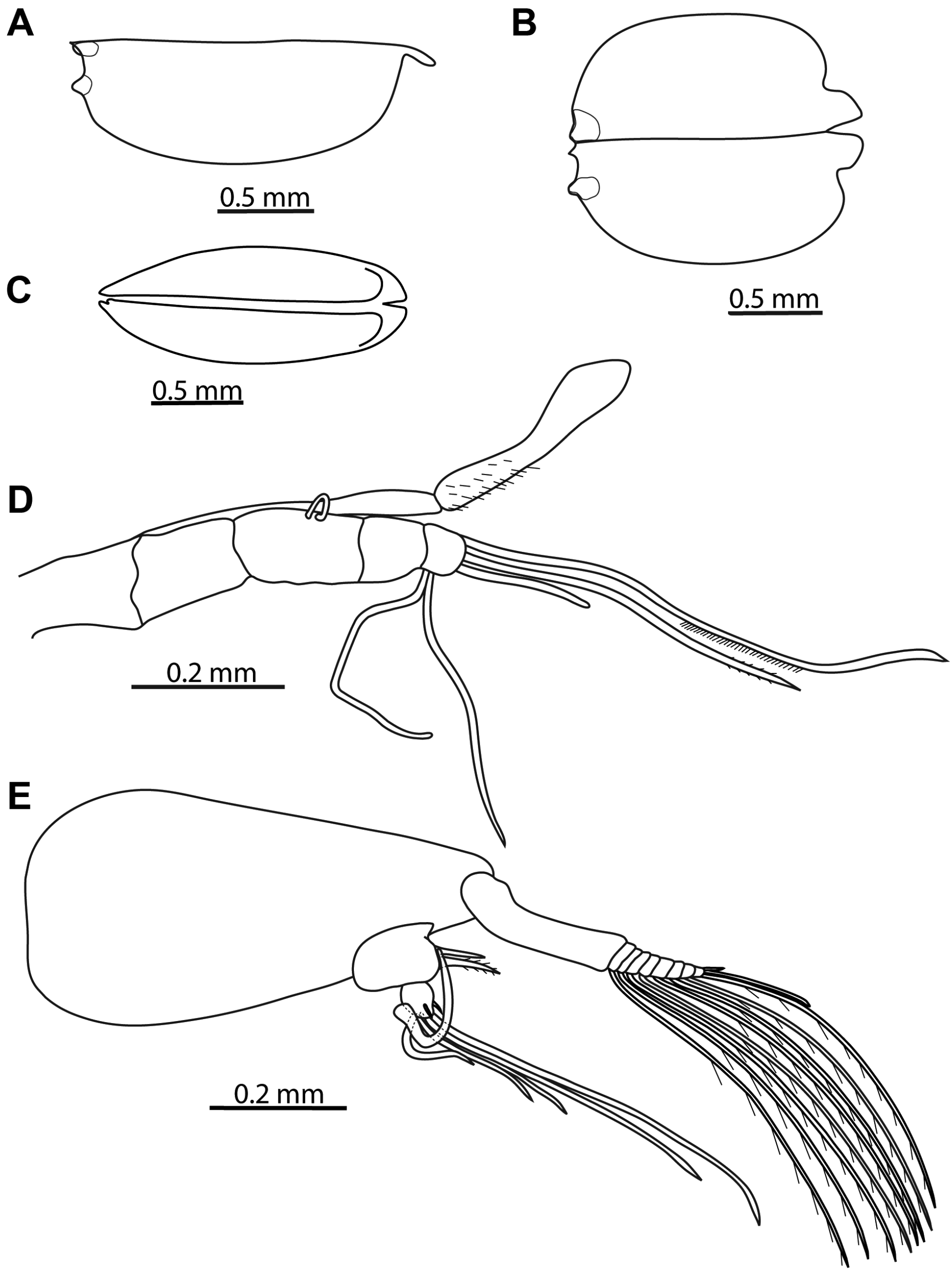


Figure 9. *Mamilloecia indica* male gen. nov., sp. nov.: (A) Lateral view; (B) carapace dissected and viewed dorsally; (C) ventral view; (D) first antenna and frontal organ; (E) second antenna.

of right carapace tubercular bulge containing asymmetric gland which opens at apex. Posterior dorsal corner of right valve furnished with small pointed spine. Just below posterior dorsal corner of left valve furnished with blunt tubercle with opening of asymmetric gland.

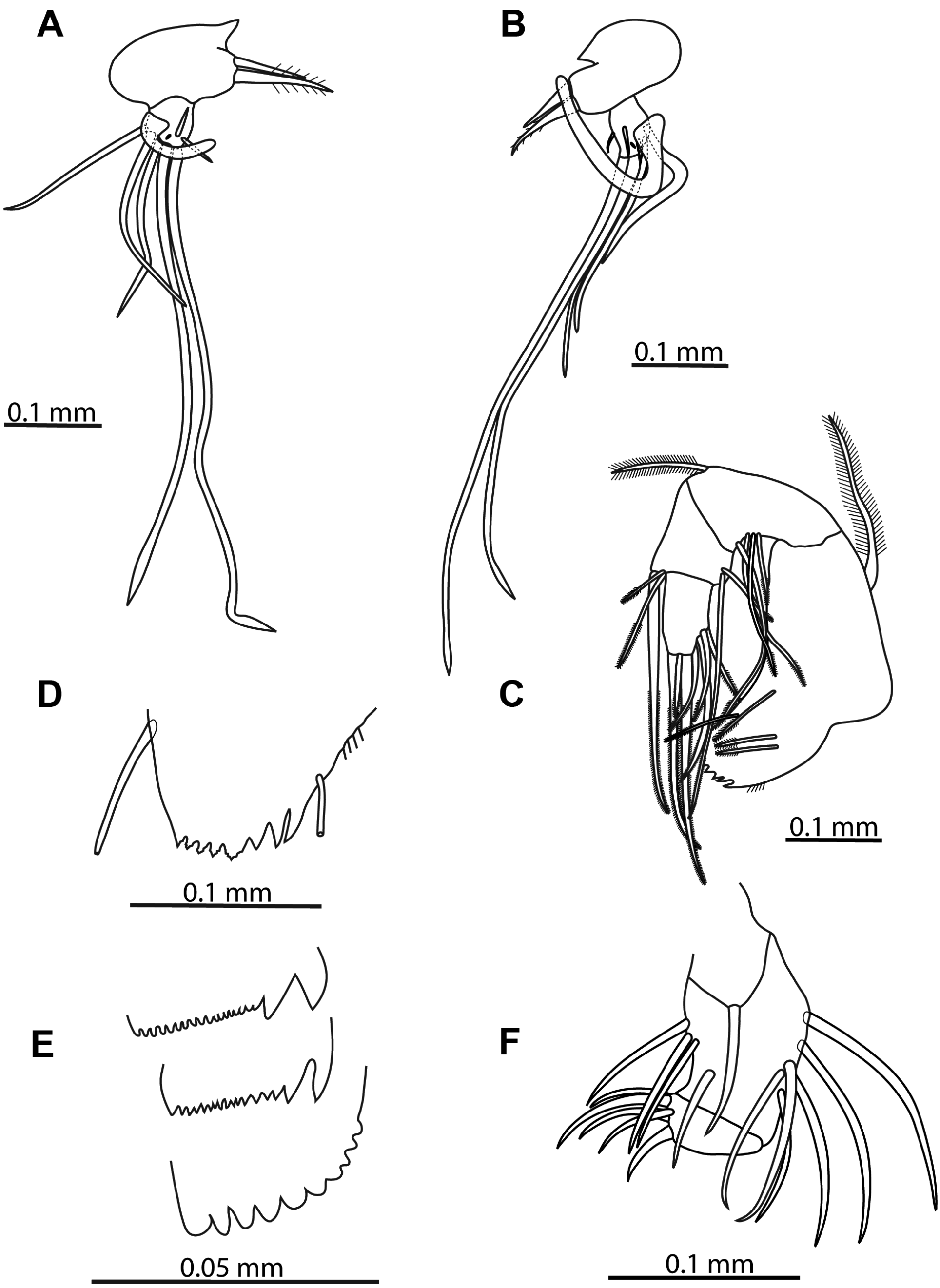


Figure 10. *Mamilloecia indica* male gen. nov., sp. nov.: (A) Left endopodite of second antenna; (B) right endopodite of second antenna; (C) mandible; (D) basal endite of mandible; (E) tooth lists; F. maxilla.

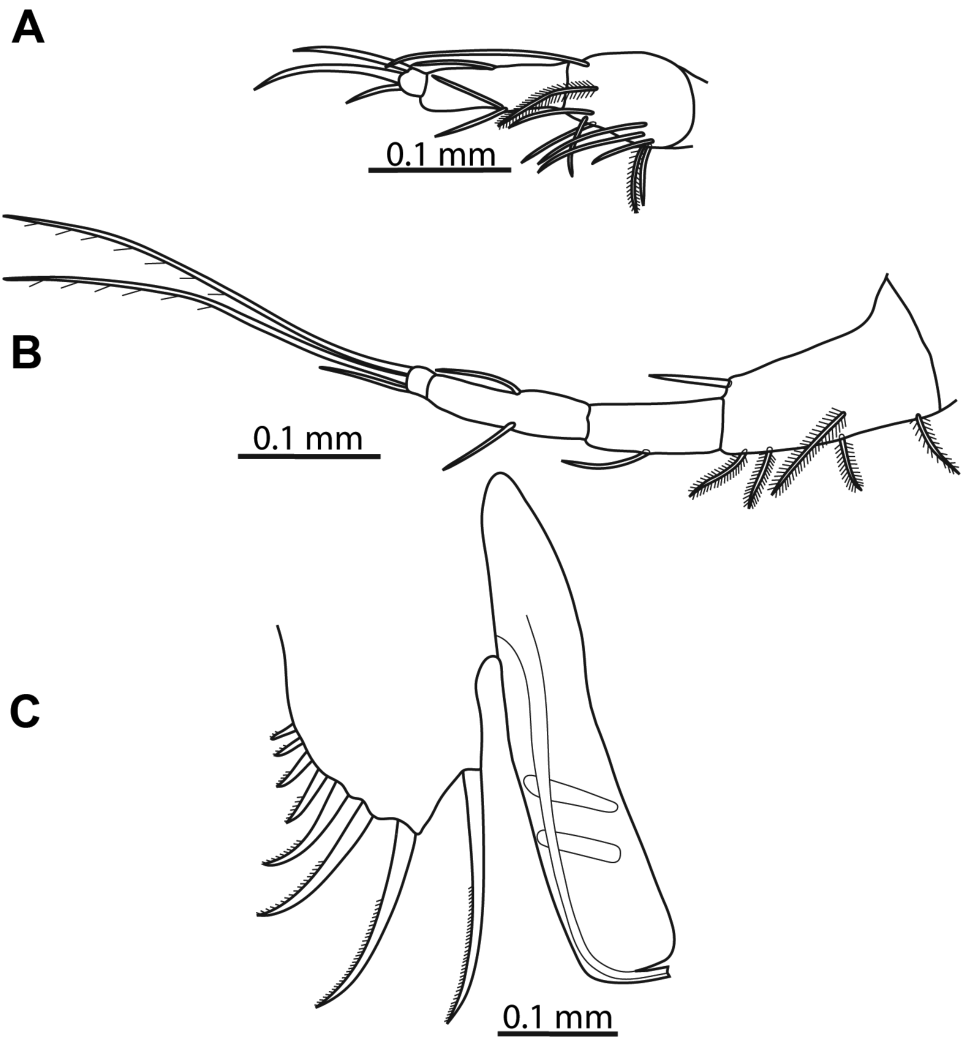


Figure 11. *Mamilloecia indica* male gen. nov., sp. nov.: (A) Fifth limb; (B) sixth limb; (C) caudal furca.

Frontal organ (Table 5; Figure 7D). Frontal organ stem slender, almost straight and longer than limb of first antenna. Capitulum with wide rounded end: dorsal surface naked; distal end of ventral surface covered in small spines. Total length 37.5%CL, much longer than first antenna.

First antenna (Table 6; Figure 7D). Five-segmented. Limb length 22.8%CL. Third segment with dorsal seta 6.0%CL. Fifth segment with five unequal setae; a-seta 14.1%CL; b-seta 14.7%CL; c-seta 14.7%CL; d-seta 15.8%CL; e-seta 20.9%CL with long hairs.

Second antenna (Table 6; Figure 7E). Protopodite 39.4%CL. First exopodite segment about half length of protopodite. Most swimming setae similar in length to protopodite, all but shortest two setae with long hairs distally. Endopodite (Figure 7F) with short, pointed a-seta; b-seta pointed and bare; no c-, d- or e-setae; f- and g-setae, respectively, 16.8%CL and 20.4%CL; h-seta 11.7%CL; i-seta 14.0%CL; j-seta 12.1%CL.

Mandible (Table 7; Figure 8A–C). Coxale toothed edge of pars incisiva with 10 large blunt teeth. Distal tooth list with two large and about 15 small pointed teeth. Proximal tooth list slightly narrower, with two large teeth and about 18 small pointed teeth. Outer margin of toothed edge of basal endite with two large dagger-shaped teeth, second with rounded tip, one pointed tooth and five subserrate teeth. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with plumose dorsal seta and four finely spinose ventral setae. Second segment with two ventral and three dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla (Table 7; Figure 8D). Basal segment with six anterior, one lateral and four posterior setae. Distal segment comparatively short and wide with five bare terminal claw setae, posteriormost longest.

Fifth limb (Table 8; Figure 8E). Ventrally basale with one plumose and five spinose setae, laterally one plumose and two bare setae, dorsally single long spinose seta – remnant of exopodite. First segment with two ventral setae and one dorsal seta, all spinose. Second segment with three unequal, curved terminal claw setae; middle claw longest 4.9%CL.

Sixth limb (Table 8; Figure 8F). Basale with five plumose ventral setae, laterally one plumose seta and one bare seta dorsally. First endopodite segment with one ventral spinose seta. Second segment with one spinose seta ventrally and one dorsally. Third segment with three unequal spinose, terminal claw setae; middle claw longest 11.0%CL.

Caudal furca (Table 8; Figure 8G). Eight pairs of claw setae diminishing in size dorsally; longest claw 11.4%CL.

Description of male

Carapace (Figure 9A–C). Mean length 1.63 ± 0.04 mm ($n = 100$). Carapace of exemplar specimen (Table 9) length 1.56 mm; height 0.60 mm; breadth 0.64 mm. Height: length ratio 38.5%CL, breadth: length ratio 41.0%CL. In lateral view carapace faintly sculptured as in female, maximum height just anterior to mid-length. Ventral margin curving smoothly into posterior margin at similar angle to anterior margin. At mid-height on posterior margin of right valve tubercular bulge containing asymmetric gland. Posterior dorsal corner of right valve furnished with small pointed spine. Posterior dorsal corner of left valve furnished with blunt process with opening of asymmetric gland.

Frontal organ (Table 9; Figure 9D). Frontal organ stem straight; shorter than limb of first antenna. Capitulum long, with bulbous distal end. Dorsal surface bare, but proximal ventral surface covered in small spines. Total length 44.2%CL, much longer than first antenna.

First antenna (Table 10; Figure 9D). With five segments. Limb length 38.5%CL. Third segment with dorsal seta 4.6%CL. Fifth segment with five unequal setae; a-seta 19.9%CL; b-seta 33.0%CL; c-seta 9.9%CL; d-seta with short fine hairs 29.5%CL; e-seta 42.3%CL with long hairs.

Second antenna (Table 10; Figure 9E). Protopodite 46.5%CL. Length of first exopodite segment about one-third length of protopodite. All swimming setae shorter than protopodite, all but shortest two setae with long hairs distally. Endopodite with short, pointed, bare a-seta; b-seta pointed with hairs; c-, d- and e-setae all very short; f- and g- setae, respectively, 35.9%CL and 29.2%CL terminally flattened; h-seta short 7.7%CL; i-seta 16.3%CL; j-seta 13.8%CL. Right endopodite (Figure 10B) with elongated clasping organ in form of hook with long proximal shank and very long curved end piece 10.1%CL. Left endopodite (Figure 10A) 'hook' much shorter and curved 5.3%CL.

Mandible, maxilla and fifth limb (Table 11, 12; Figures 10C–F, 11A). Structure and arrangement of setae for mandible, maxilla and fifth limb same as in female.

Sixth limb (Table 12; Figure 11B). Basale with five plumose setae ventrally, one lateral plumose seta and one bare dorsal exopodal seta. First endopodite segment with single, ventral seta. Second endopodite segment with one seta ventrally and one dorsally. Third segment with three terminal setae, two very long, evenly curved ventrally with long hairs 22.1%CL and one bare much shorter seta 4.2%CL.

Caudal furca (Table 12; Figure 11C). Structure and arrangement of furcal claws similar to female; longest claw 14.3%CL.

Intromittent organ (Table 12; Figure 11C). Male copulatory appendage exceptionally long, 26.9%CL, with two oblique muscles.

Remarks

The distinctive features of *M. indica* are: tubercle at mid-height on posterior margin with rounded opening; maximum height anterior to mid-length; considerable size difference between female and male (Figures 7, 9).

Mamilloecia mamillata (Müller, 1906) comb. nov.
(Figures 12–16)

Conchoecia mamillata Müller, 1906: 60, pls 16, 1–9; 35, 8, Müller 1906: 66. (Südpolar), Müller, 19–12, Granata and Caporiacco, 1949: 30, Iles, 1953: 269, Rudjakov, 1962: 175, fig. 1a–e, Deevey, 1968: 36, fig. 12d–f, Deevey and Brooks, 1980: 66, figs 11e–h; 12a; 13b,e–j, Angel, 1981: 559, fig. 194.

Paraconchoecia mamillata (part) Poulsen, 1973: 42–43, fig. 16a–j.

Material

The material was collected from *Discovery* station 9022 (see above). Permanent preparations of dissected specimens used to prepare the illustrations in this paper have been deposited in the collections of the Natural History Museum, London: registration number NHMUK 2011 1637 for the female on slides and NHMUK 2011.1638 for the male on slides. The 53 females and 40 males that were measured are retained in 80% industrial methylated ethanol registration numbers NHMUK 2011.1639–1648.

Description

A full description is merited here as the species has not been comprehensively illustrated and it is being transferred to the new genus of *Mamilloecia*. The morphological

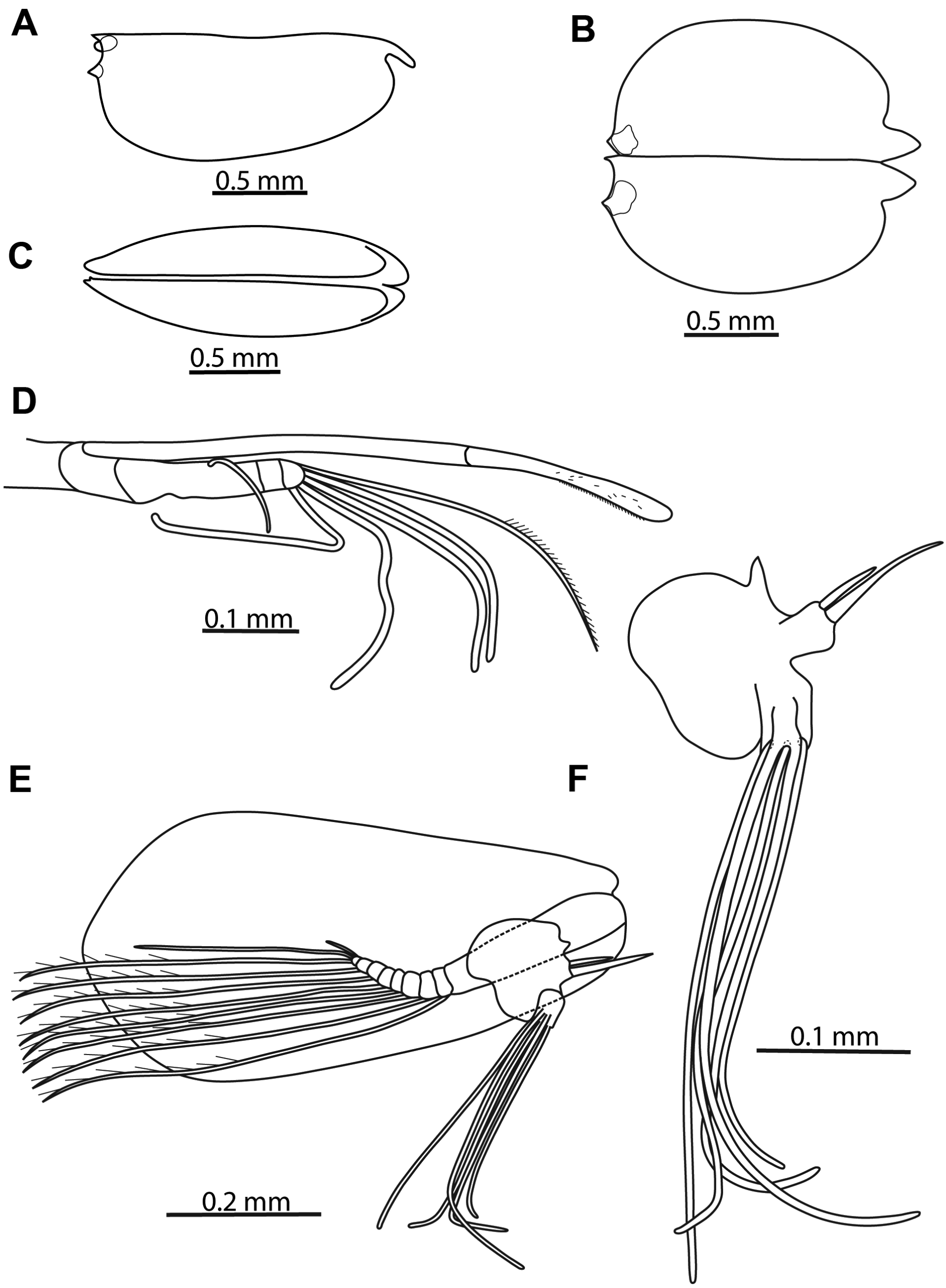


Figure 12. *Mamilloecia mamillata* comb. nov. female: (A) Lateral view; (B) carapace dissected and viewed dorsally; (C) ventral view; (D) first antenna and frontal organ; (E) second antenna; (F) endopodite.

characters of the carapaces and internal structures of both sexes are listed in Tables 5–12, together with comparative data for the other species described here.

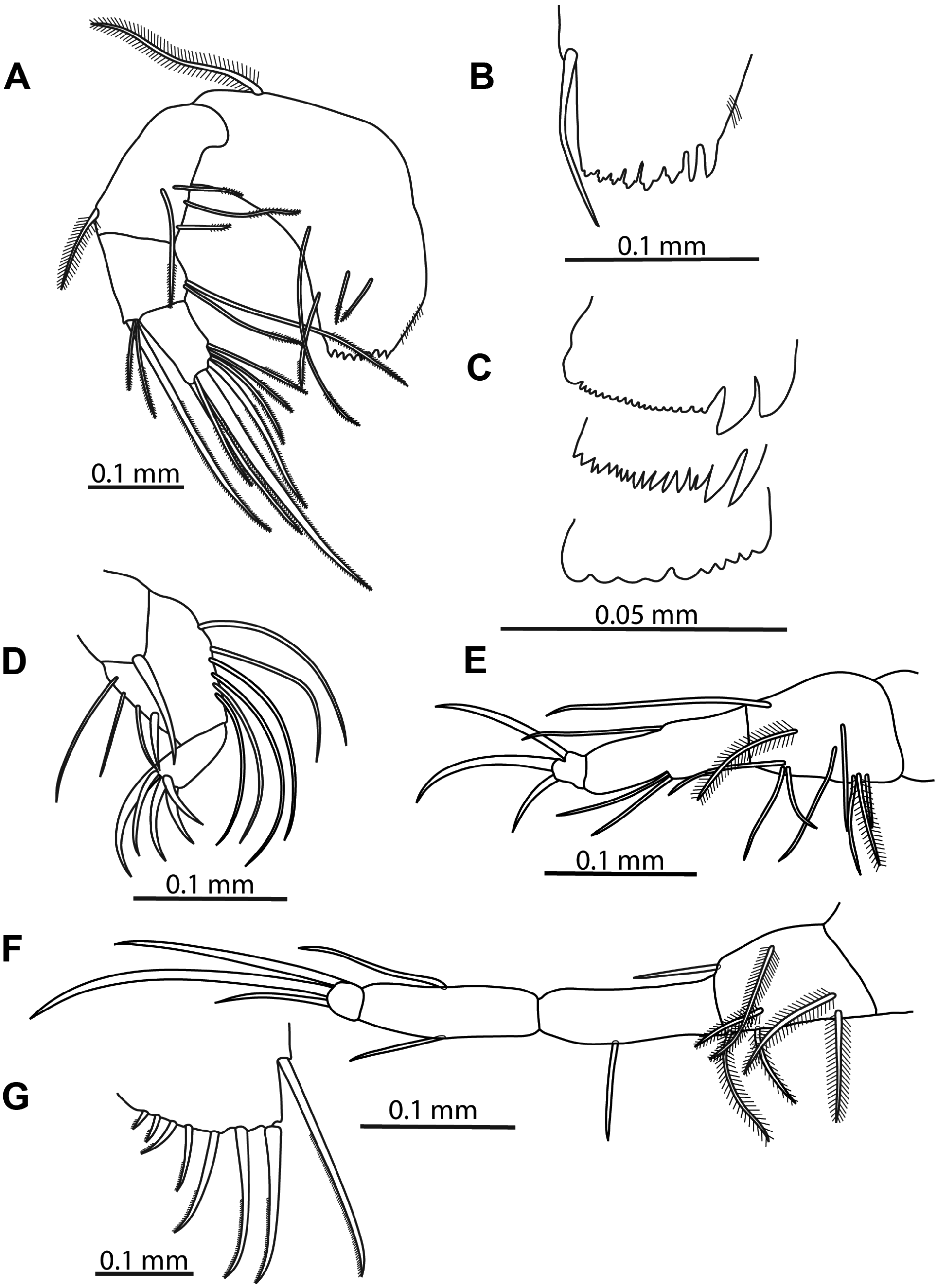


Figure 13. Mamilloecia *mamillata* comb. nov. female: (A) Mandible; (B) basal endite of mandible; (C) tooth lists; (D) maxilla; (E) fifth limb; (F) sixth limb; (G) caudal furca.

Description of female

Carapace (Figure 12A–C). Mean length 1.75 ± 0.03 mm ($n = 53$). Carapace of exemplar specimen (Table 5) length 1.74 mm; height 0.68 m; breadth 0.56 mm. Height :

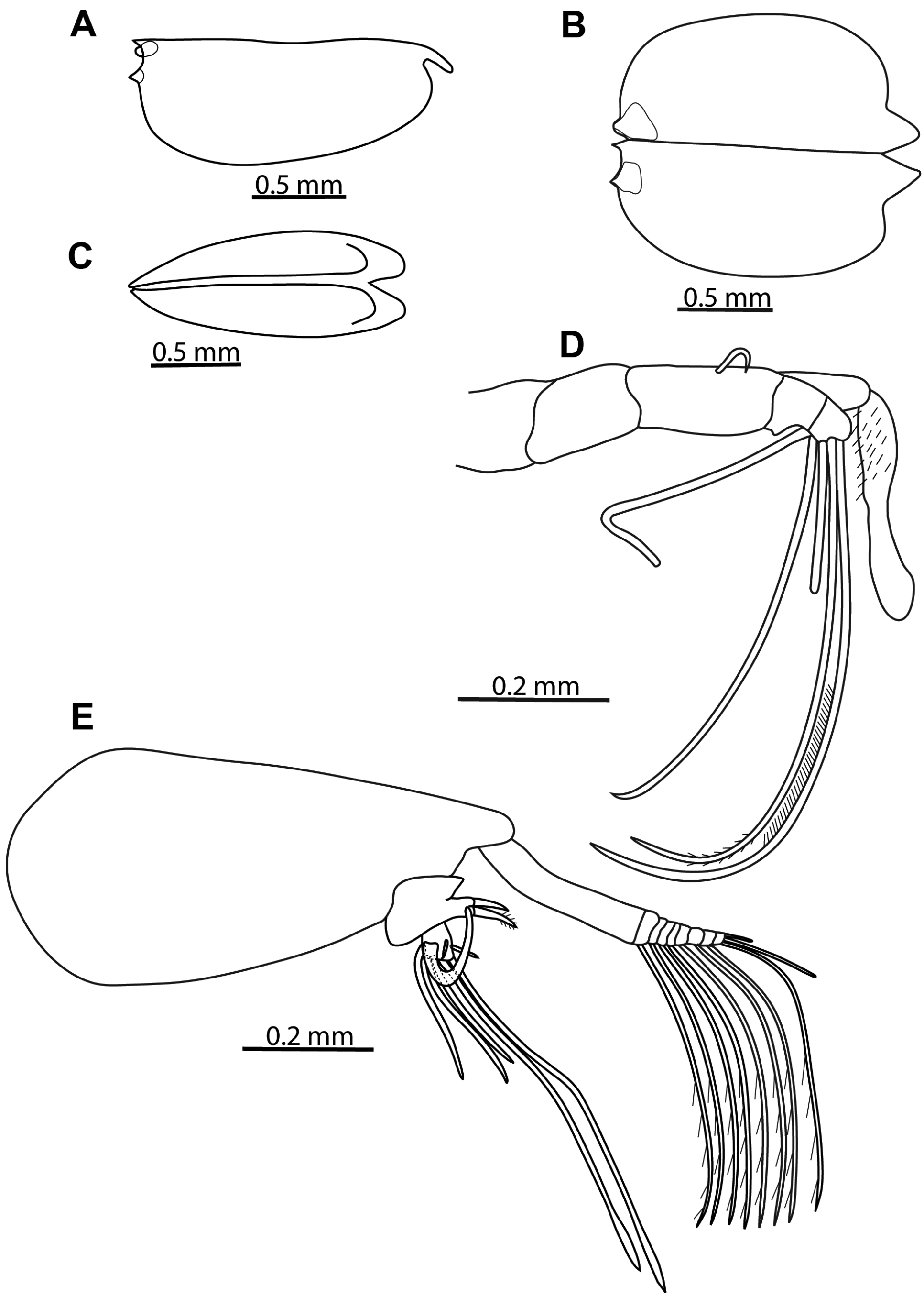


Figure 14. *Mamilloecia mamillata* comb. nov. male: (A) Lateral view; (B) carapace dissected and viewed dorsally; (C) ventral view; (D) first antenna and frontal organ; (E) second antenna.

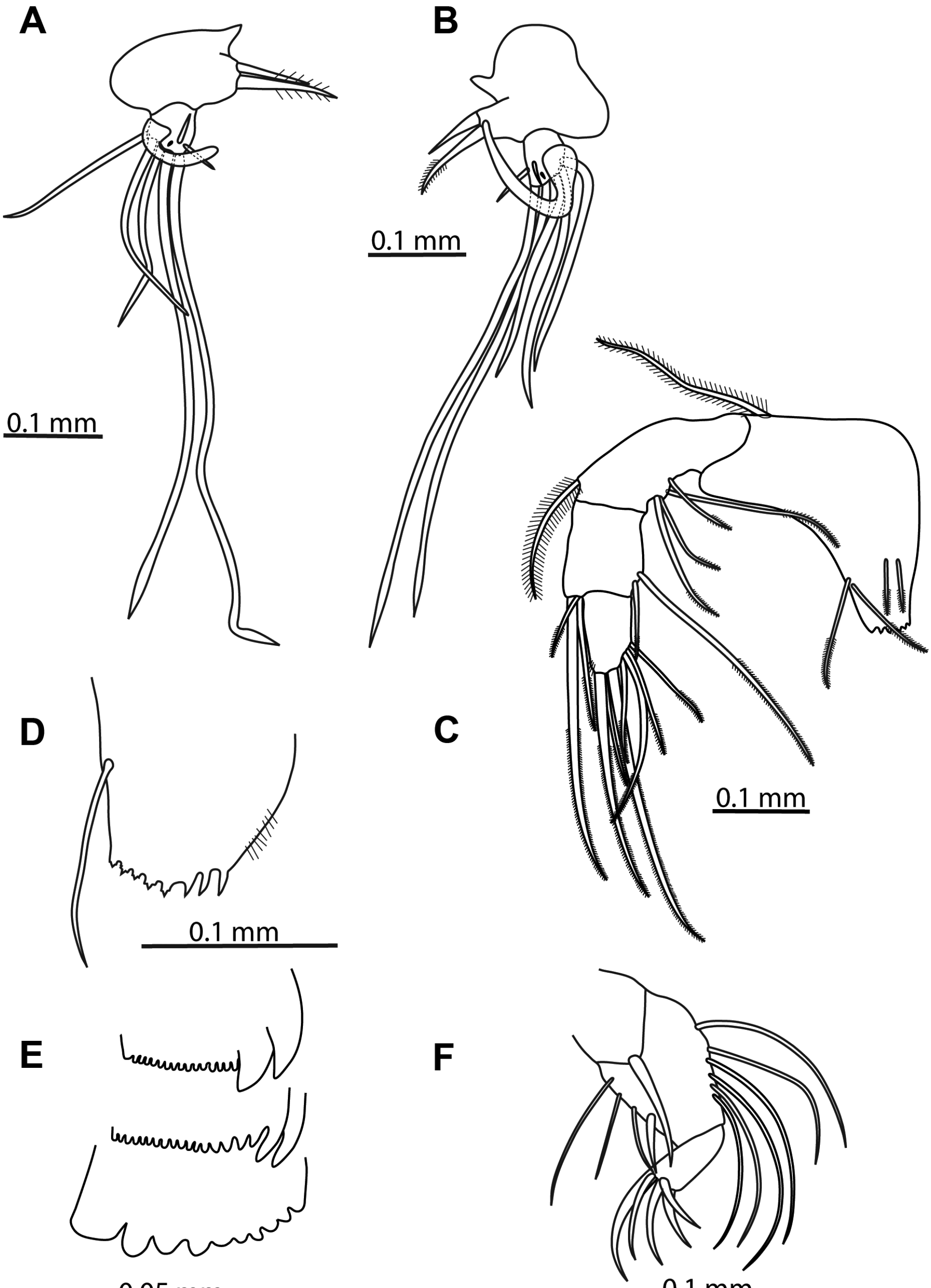


Figure 15. *Mamilloecia mamillata* comb. nov. male: (A) Left endopodite of second antenna; (B) right endopodite of second antenna; (C) mandible; (D) basal endite of mandible; (E) tooth lists; (F) maxilla.

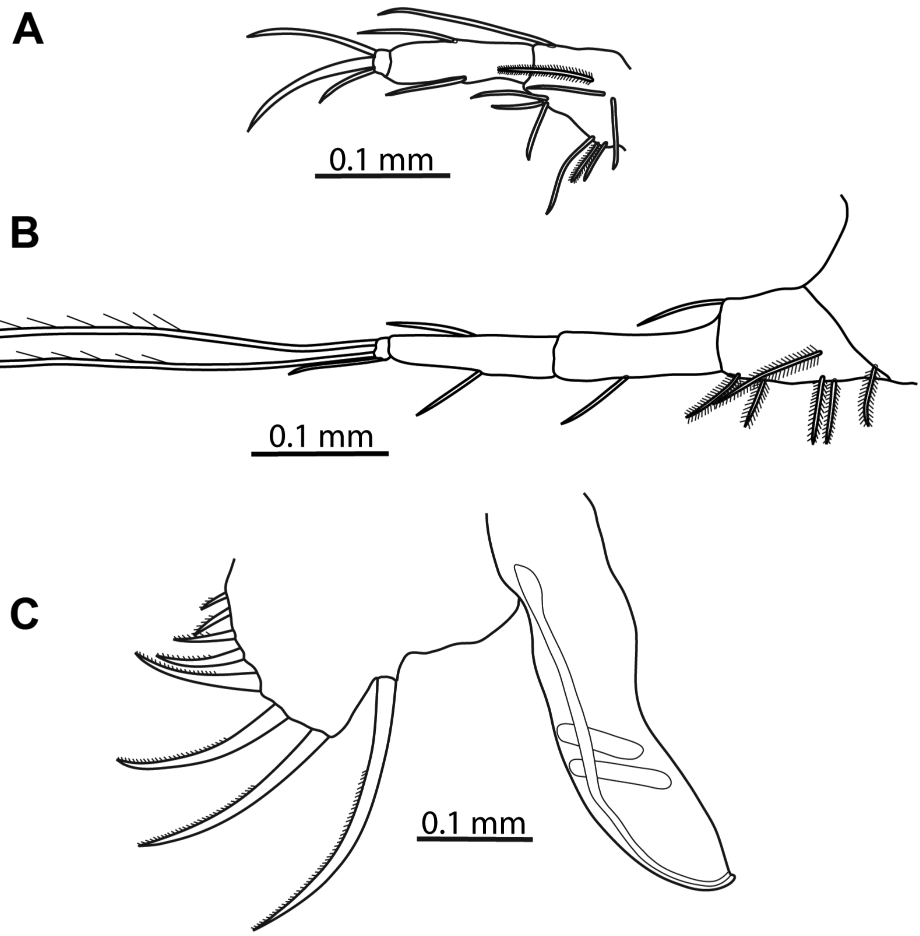


Figure 16. *Mamilloecia mamillata* comb. nov. male: (A) Fifth limb; (B) sixth limb; (C) caudal furca.

length ratio 39.1%CL, breadth: length ratio 32.2%CL. In lateral view carapace faintly sculpted with parallel lines running at approximately 45° to ventral surface. Carapace elongate, maximum height posterior to mid-length. Ventral margin curving smoothly into posterior margin. On posterior margin of right carapace tubercular bulge with asymmetric gland. Posterior dorsal corner of right valve furnished with small pointed spine. Posterior dorsal corner of left valve furnished with blunt process and opening of asymmetric gland.

Frontal organ (Table 5; Figure 12D). Frontal organ stem slender, almost straight and longer than limb of first antenna. Capitulum with rounded end and bare dorsal surface, distal end of ventral surface covered in small spinules. Total length 34.9%CL, much longer than first antenna.

First antenna (Table 6; Figure 12D). Five-segmented. Limb length 16.8%CL. Third segment with dorsal seta 5.8%CL. Fifth segment with five unequal setae; a-seta 16.7%CL; b-seta 17.8%CL; c-seta 17.2%CL; d-seta 16.7%CL; e-seta 26.1%CL with long hairs.

Second antenna (Table 6; Figure 12E). Protopodite 32.3%CL. First exopodite segment about half length of protopodite. Most swimming setae similar in length to protopodite, all but shortest two setae have long hairs distally. Endopodite (Figure 12F) a-seta short, pointed bare; b-seta pointed with hairs; no c-, d- or e-setae; f- and g- setae respectively 20.8%CL and 23.9%CL; h-seta 17.0%CL; i-seta 19.7%CL; j-seta 18.7%CL.

Mandible (Table 7; Figure 13A–C). Coxale toothed edge of pars incisiva with 10 large blunt teeth. Distal tooth list with two large and about 15 small pointed teeth. Proximal tooth list slightly narrower with two large teeth and about 18 small pointed teeth. Outer margin of toothed edge of basal endite with two large dagger-shaped teeth, second with rounded tip, one pointed tooth and five subserrate teeth. Exopodite represented by moderately long plumose seta inserted on outer margin of basis. First endopodite segment with plumose dorsal seta and four finely spinose ventral setae. Second segment with two ventral and three dorsal setae, all finely spinose. Third segment with seven spinose terminal setae; one very long and robust.

Maxilla (Table 7; Figure 13D). Basal segment with six anterior, one lateral and four posterior setae. Distal segment comparatively short and wide with five bare terminal claw setae, posteriormost longest.

Fifth limb (Table 8; Figure 13E). Ventrally basale with one plumose and five spinose setae, laterally one plumose and two bare setae, dorsally one long seta. First segment with two ventral setae and one dorsal seta. Second segment with three unequal, curved terminal claw setae; middle claw longest 5.6%CL.

Sixth limb (Table 8; Figure 13F). Basale with five plumose ventral setae, laterally one plumose seta and one bare seta dorsally. First endopodite segment with one ventral spinose seta. Second segment with one spinose seta ventrally and one dorsally. Third segment with three unequal spinose, terminal claw setae; middle claw longest 10.5%CL.

Caudal furca (Table 8; Figure 13G). Eight pairs of claw setae diminishing in size dorsally; longest claw 9.3%CL.

Description of male

Carapace (Figure 14A–C). Mean length 1.69 ± 0.04 mm ($n = 40$). Carapace of exemplar specimen (Table 9) length 1.72 mm; height 0.64 mm; breadth 0.62 mm. Height : length ratio 37.2%CL, breadth : length ratio 36.0%CL. In lateral view carapace faintly sculpted as in female, maximum height posterior to mid-length. Ventral margin curving smoothly into posterior margin. On posterior margin of right valve tubercular bulge containing asymmetric gland. Posterior dorsal corner of right valve furnished with small pointed spine. Posterior dorsal corner of left valve furnished with blunt process on which asymmetric gland opens.

Frontal organ (Table 9; Figure 14D). Frontal organ stem straight and similar in length to limb of first antenna. Capitulum long, with bulbous distal end. Dorsal surface bare, but proximal ventral surface covered in small spinules. Total length 43.3%CL, much longer than first antenna,

First antenna (Table 10; Figure 14D). Five-segmented. Limb length 37.1%CL. Third segment with dorsal seta 5.7%CL. Fifth segment with five unequal setae; a-seta

24.1%CL; b-seta 38.4%CL; c-seta 11.6%CL; d-seta with short fine hairs 38.4%CL; e-seta 40.7%CL with long hairs.

Second antenna (Table 10; Figure 14E). Protopodite 42.2%CL. First exopodite segment about one-third length of protopodite. All swimming setae shorter than protopodite, all but shortest two setae have long hairs distally. Endopodite a-seta short, pointed, bare; b-seta pointed with hairs; c-, d- and e-setae all very short; f- and g-setae respectively 35.8%CL and 33.7%CL; h-seta short 11.6%CL; i-seta 12.9%CL; j-seta 12.4%CL. Right endopodite (Figure 15B) with elongated clasping organ in form of hook with long proximal shank and very long curved end piece 6.8%CL. Left endopodite (Figure 15A) 'hook' much shorter and curved 4.3%CL.

Mandible, maxilla and fifth limb (Tables 11, 12; Figures 15C–F, 16A). Structure and arrangement of setae for mandible, maxilla and fifth limb as for female.

Sixth limb (Table 12; Figure 16B). Basale with five plumose setae ventrally, one laterally and one bare dorsal exopodal seta. First endopodite segment with one ventral seta. Second endopodite segment with single seta both ventrally and dorsally. Third segment with three terminal setae; two very long, evenly curved ventrally with long hairs 23.0%CL and one much shorter seta 3.8%CL.

Caudal furca (Table 12; Figure 16C). Structure and arrangement of furcal claws similar to female. Longest claw 14.2%CL.

Intromittent organ (Table 12; Figure 16C). Male copulatory appendage exceptionally long, 29.7%CL, with two oblique muscles.

Remarks

The carapace shape (Figures 7, 9, 12, 14) and measurements (Tables 5–12) of the two species of *Mamilloecia* differ significantly. The maximum height of the carapace in both sexes of *M. mamillata* is posterior to mid-length, whereas in both sexes of *M. indica* it is anterior. The tubercle of both sexes of *M. mamillata* is pointed and positioned about two-thirds of the way along the posterior margin nearer to the posterior dorsal corner, but in *M. indica* it is rounded and positioned at about mid-height. In *M. mamillata* there is not such a significant difference in length between males and females as in *M. indica*.

The principal component analysis for both the Atlantic form and the Oman form of *Mamilloecia* females (Table 3) produced an eigenvalue of 2.479 that translated to $\sim$ 50% variation between individuals. For males (Table 3) an eigenvalue of 3.090 translated to $\sim$ 62% variation between individuals. The component matrix (Table 4) shows the weightings allocated to each of the variables for the extracted factors. For the females, the results from the component matrix suggest that the best contrast between individuals is obtained by comparing length of rostrum to posterior dorsal corner with length of posterior dorsal corner to below tubercle, i.e. individuals that are longer from rostrum to posterior dorsal corner are shorter from posterior dorsal corner to below tubercle and vice versa. For the males (Table 4), the results suggest that the best contrast between individuals is obtained by comparing the length from rostrum to posterior dorsal corner with height, i.e. individuals that are longer from rostrum to posterior dorsal corner show the greatest height and vice versa. The x-axis for the scatterplots for each sex (Figures 17, 18) is derived from the weighted scores of component 1 and the *y*-axis is derived from the weighted scores of component 2. Hence, the morphological data on axis 1 correlate with length and those on axis 2 correlate with shape. Both plots show distinct separation of forms, although there is a little overlap. The principal component analysis of the morphometric characters of the carapace (Figures 17, 18) provides strong evidence supporting the inference that the two forms are distinct species. The Oman form is here recognized as a new species, *M. indica*. In both sexes the length of the frontal organ and length of the first antenna is significantly longer in *M. indica*, but most setae of the first antenna are longer in *M. mamillata* (Tables 6, 10). In the male both right and left clasper shank lengths are significantly longer in *M. indica* (Table 10).

Discussion

The carapace and morphologies of the two *Mamilloecia* species examined herein are substantially different from *P. spinifera*. The carapaces of both sexes of *P. spinifera* have high shoulder vaults (Figures 2A, 4A), lack tubercles on the posterior margin of either valve and the position of the right asymmetric gland opens anterior to the back of the hinge between the two valves near the posterior ventral corner. In contrast, the carapace of *M. indica* (Figure 7A) has low rounded shoulder vaults, has a tubercle at mid-point along the posterior edge of the right valve with the asymmetric gland opening at its apex. The frontal organ of both sexes of *P. spinifera* has a pointed capitulum distally (Figures 2D, 4D), but both sexes of both species of *Mamilloecia* have a rounded capitulum (Figures 7D, 9D, 12D, 14D). The armature of the male e-seta on the first antenna of *P. spinifera* is in the form of paired spines (Figure 4D), whereas the two species of *Mamilloecia* (Figures 9D, 14D) have fine hairs. In the male of *P.spinifera* the g-, h-, i- and j-setae of the second antenna are significantly longer than the male setae of either species of *Mamilloecia* (Table 10). In both sexes of *P. spinifera* the pars incisiva on the mandible has nine teeth; the pars incisiva of *Mamilloecia* has 10 teeth. On the maxilla of both sexes of *P. spinifera* two of the six anterior setae of the basal segment are plumose, but in *Mamilloecia* all six setae are bare (Tables 7, 11). The fifth limb of the male *P. spinifera* has six ventral setae on the basale; the male of both species of *Mamilloecia* has five (Figures 6A, 11A, 16A), and on the sixth limb all terminal setae of *P. spinifera* are long and equal, but *Mamilloecia* has one much shorter terminal seta (Figures 6B, 11B,16B). Collectively, this evidence supports the establishment of a new genus, *Mamilloecia*, to include *M. indica* and *M. mamillata*, together with *M. nanomamillata* (Deevey and Brooks 1980) another closely related species from the subtropical Atlantic.

After sequencing the cytochrome oxidase I gene, *COI*, of more than 70 species of planktonic ostracods Angel (personal communication.) confirmed that shape and size are a good indication of species differentiation. However, the specimens studied herein could not be used for sequencing studies because they had been fixed and preserved with formaldehyde, which fragments DNA. The principal component analysis, on a total of 80 individuals, showed convincing evidence for the separation of the two species of *Mamilloecia*. Figure 17 for the females and Figure 18 for the males show two distinct clusters. This indicates that *M. indica* is a separate species from *M. mamillata*. This method has not previously been used for separating species of ostracods. Schwartz et al. (1985) used principal component analysis for separating *Daphnia pulex* from *Daphnia obtusa*, a freshwater branchiopod crustacean of similar

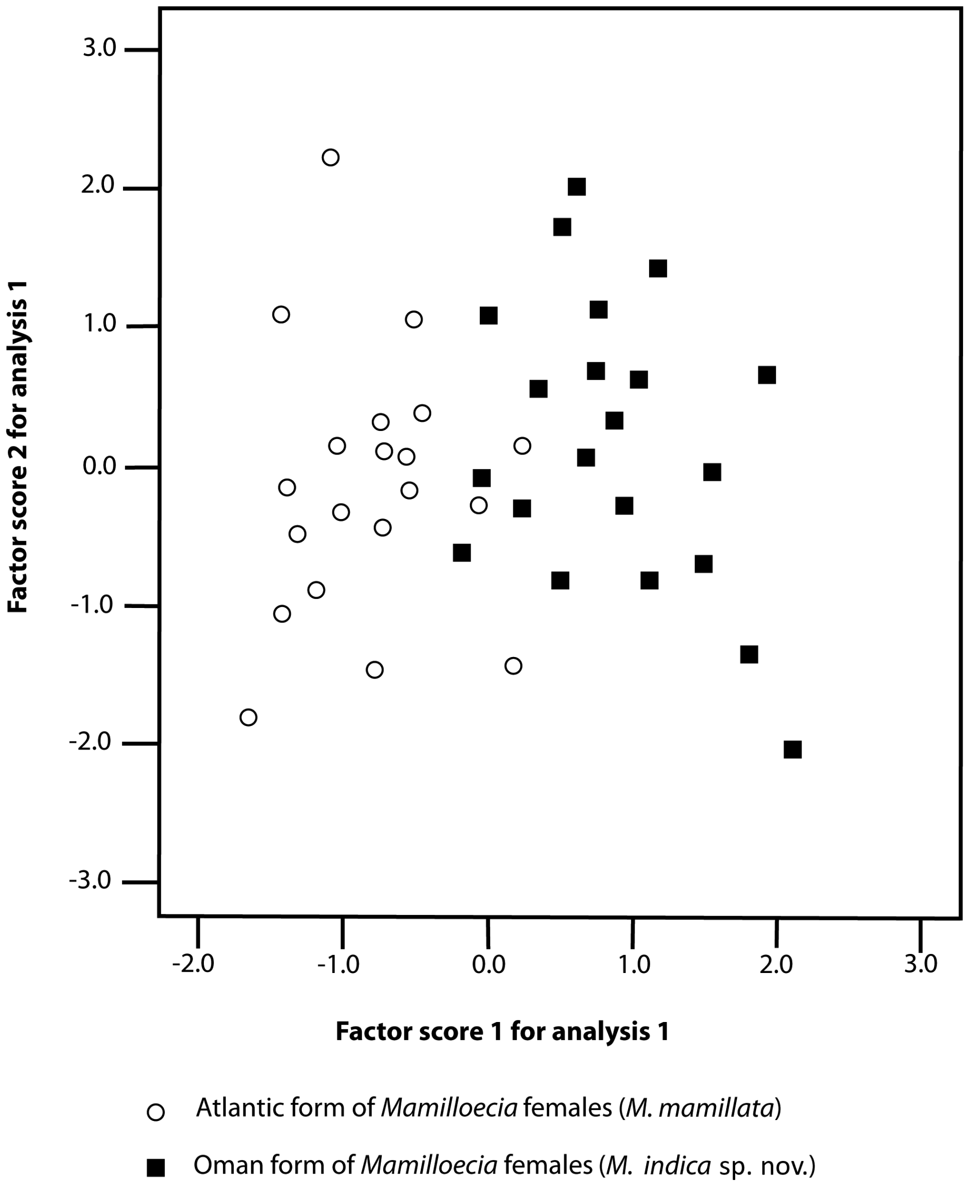


Figure 17. Scatterplot of principal component analysis of both forms of *Mamilloecia* females.

shape and size to an ostracod. The authors measured five morphological characteristics from 790 individuals from 12 North American sites and two English sites. Scatterplots of these measurements showed two distinct clusters. Based on these clusters the authors assigned the species names *Daphnia pulex* and *Daphnia obtusa*. More recently, Hoskin and Higgie (2008) used principal component analysis to provide evidence of a new species of velvet gecko from Queensland Australia, using seven morphological characteristics on 33 individuals.

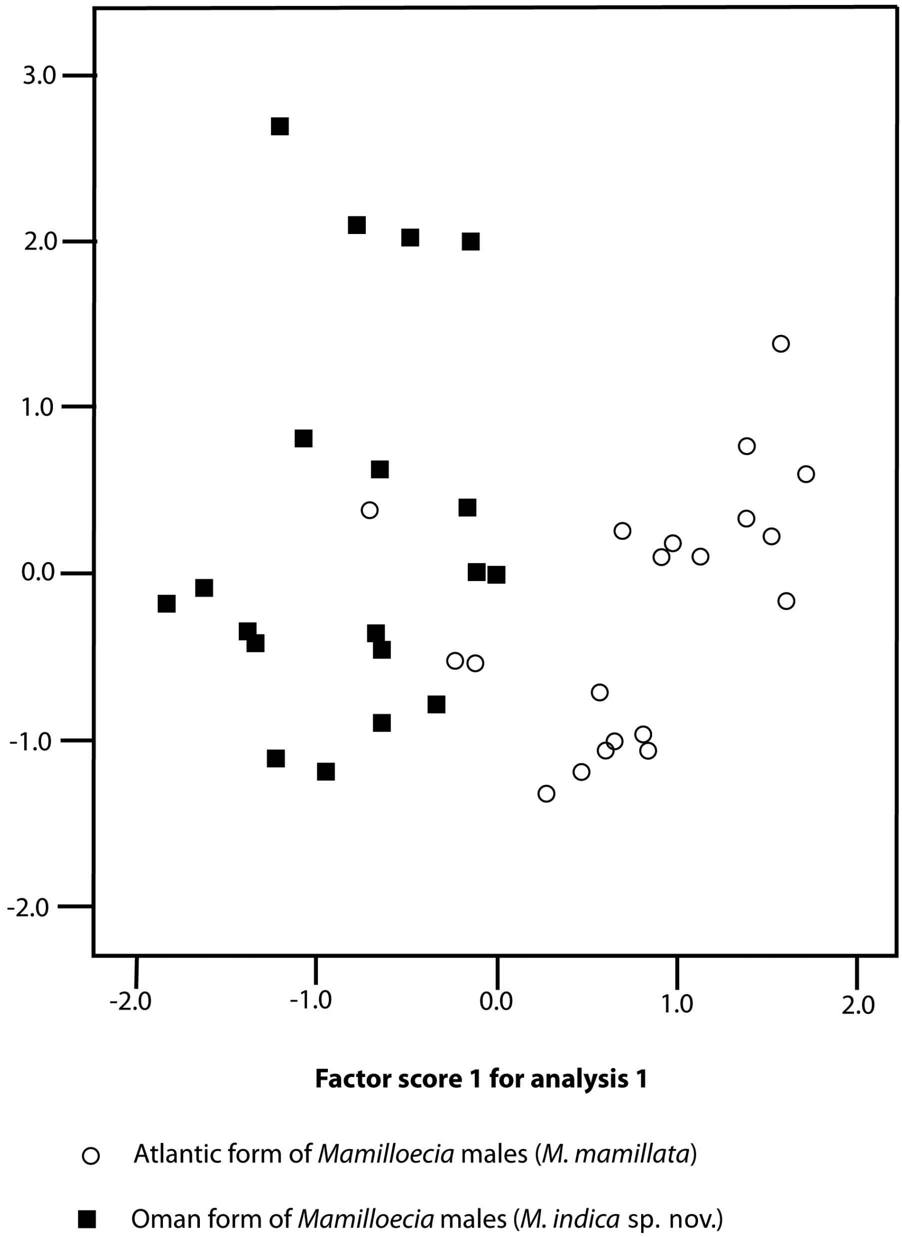


Figure 18. Scatterplot of principal component analysis of both forms of *Mamilloecia* males.

Females similar to *M. mamillata* have been sampled at much greater depths (over 3000 m) at *Discovery* Station 9131 (20°7′ N 21°32′ W) and are also larger and different in shape, suggesting that they represent yet another cryptic species in the Atlantic.

Acknowledgements

I am very grateful to Dr Martin Angel of the Southampton Oceanography Centre for all his help and support, and to Professor Geoff Boxshall and the staff at the Natural History Museum, London for providing the material. I especially thank my husband Raymond Graves for his help with the tables, constructive criticism of the paper and continual support.

References

Angel MV. 1981. Ostracoda. Atlas del zooplankton del Atlantico suboccidental y metodos de trabajo con el zooplancton marino, D. Boltovskoy (ed.), Mar del Plata, Argentina: INIDEP. 543–585.

Angel MV. 1993. Pelagic Marine Ostracoda. Synopses of the British Fauna (New Series), D.M. Kermack, R.S.K. Barnes and J.H. Crothers (eds), 48, published for Linnean Society of London and The Estuarine and Coastal Sciences Association by the Field Studies Council. 1–239.

Angel MV, Blachowiak-Samolyk K. 2006. *Obtusoecia* (Halocyprida: Myodocopa: Ostracoda) a bipolar planktonic oceanic genus: taxonomy, bathymetry and zoogeographical distribution. Ann Zool (Warsz). 56(1):1–48.

Angel MV, Blachowiak-Samolyk K, Drapun I, Castillo R. 2007. Changes in the composition of planktonic ostracod populations across a range of latitudes in the North-east Atlantic. Prog Oceanogr. 73(1):60–78.

Brady GS, Norman AM. 1896. A monograph of marine and freshwater Ostracoda of the North Atlantic and of Northwest Europe Pt II, Sections ii to iv: Myodocopa, Cladocopa, and Platycopa. Trans R Dubl Soc. (*N.S.*) 5:621–746.

Chen R, Lin J. 1995. Pelagic Ostracoda in China Seas. (In Chinese), ISBN 7-5027-4091-0/Q-115, 134.

Claus C. 1891. Die Halocypriden des Atlantisches Oceans und Mittelmeres. Vienna: Alfred Hölder. p. 1–81.

Deevey GB. 1968. Pelagic ostracods of the Sargasso Sea off Bermuda. Bull Peabody Mus Nat Hist. 26:1–125.

Deevey GB. 1974. Pelagic ostracods collected on Hudson 70 between the equator and 55°S in the Atlantic, Proceedings of the Biological Society of Washington, 87:351–380.

Deevey GB. 1978a. A taxonomic and distributional study of the planktonic ostracods collected on three cruises of the Eltanin in the South Pacific and Antarctic region of the South Pacific, Biology of the Antarctic Seas, 8, Antarctic Research series. 28:43–70.

Deevey GB, Brooks AL. 1980. The planktonic ostracods of the Sargasso Sea off Bermuda: species composition and vertical and seasonal distribution between the surface and 2000 m. Bull Fl State Mus Biol Sci. 26:37–124.

Granata L, Caporiacco L. 1949. Ostracods marins recuellis pendant les croissières du Prince Albert 1er de Monaco. Resultats des campagnes, Scientific Prince Albert 1er 109:1–51.

Herring PJ, Howell PR, Roe HSJ. 1998. Scheherezade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb–30 Apr 1997. No. 11. Biomass data. Leg 1, 12 Feb–19 Mar 1997. (Unpublished manuscript).

Herring PJ, Howell PR, Pugh PR. 1999. Scheherezade – an interdisciplinary study of the Gulf of Oman, Strait of Hormuz and southern Arabian Gulf, *Charles Darwin* Cruise 104, 12 Feb–30 Apr 1997. No. 16, Fish, decapod shrimps and siphonophores: abundances and size data. Leg1. 12 Feb–Mar 1997. (Unpublished manuscript).

Hoskin CJ, Higgie M. 2008. A new species of velvet gecko (Diplodactylidae: Oedura) from north-east Queensland, Australia. Zootaxa 1788:21–36

Iles EJ. 1953. A preliminary report on the Ostracoda of the Benguela Current, Discovery Report. 26:259–280.

Leveau M. 1965. Contribution a l' étude des Ostracodes et Cladocères du Golfe de Marseille, Recueil des travaux de la Station Marine d'Endoumme-Marseille (Fax. hors. série. suppl.). 37:161–243.

Leveau M. 1967. Ostracodes pélagique du sud-ouest de l'Océan Indien (Région de Tuléar). Recueil des travaux de la Station Marine d'Endoumme-Marseille (Fax. hors. série. suppl.). 6:63–70.

Müller GW. 1906a. Ostracoda. Wissenschaftliche Ergebnisse der Deutschen Tiefsee-Expedition 'Valdivia' 1989–1899. 8:29–154.

Müller GW. 1906b. Die Ostracoden der deutschen Südpolar-Expedition 1901–1903, Deutsche Südpolar-Expedition 1901–1903, 10, (Zoology 2). 51–182.

Müller GW. 1912. Ostracoden. Das Tierreich. 31:1–434.

Poulsen EM. 1973. Ostracoda-Myodocopa, 3b. Halocypriformes-Halocypridae. Conchoeninae. Dana Rep. 84:1–223.

Roe HSJ, Shale DM. 1979. A new multiple rectangular midwater trawl (RMT1+8) and some modifications to the Institute of Oceanographic Sciences' RMT1+8. Mar Biol. 50:283–288.

Roe HSJ, Baker AdeC, Carson RM, Wild RA, Shale DM. 1980. Behaviour of the Institute of Oceanographic Sciences' rectangular midwater trawls; theoretical aspects and experimental observations. Mar Biol. 56:247–259.

Rudyakov YA. 1962. Ostracoda Myodocopa (family Halocypridae) from the N.W. Pacific Ocean, Trudy Instituta Okeanologii. 58:172–201.

Schwartz SS, Innes DJ, Herbert PDN. 1985. Morphological separation of *Daphnia pulex* and *Daphnia obtusa* in North America. Limnol Oceanogr. 30:189–197.

Skogsberg T. 1920. Studies on marine ostracods. Part 1. (Cypridinids, halocyprids and polycopids). Zool Bid Upps. Suppl. 1:1–784.

Vavra V. 1906. Die Ostracoden (Halocypriden und Cypridiniden) der Plankton-Expedition, Ergebnisse Plankton-Expedition Humboldt-Stiftung. 2:1–76.